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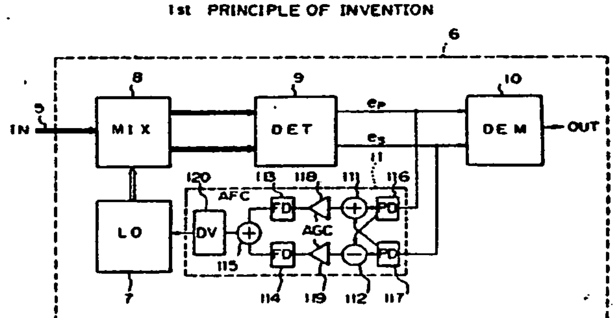
(54) Polarization diversity optical receiver for coherent optical communication.

(57) Disclosed is a polarized wave diversity optical receiver for coherent optical communication comprising: an optical local oscillating circuit (7) for oscillating local oscillating light; a mixing circuit (8) for mixing signal light and the local oscillating light to obtain two polarized components; a detecting circuit (9) for detecting the polarized components to output intermediate frequency signals (e_S and e_P); and a frequency control circuit (11) for controlling, in accordance with the intermediate frequency signals (e_S and e_P), the oscillating frequency of the optical local oscillating circuit (7). To ensure that the intermediate frequency is not disappeared, the frequency control circuit (11) outputs a combined signal of a sum and a difference of said intermediate frequency signals (e_S and e_P).

Fig. 4
1st PRINCIPLE OF INVENTION



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POLARIZATION DIVERSITY OPTICAL RECEIVER FOR COHERENT OPTICAL COMMUNICATION

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates to a polarization wave diversity optical receiver for coherent heterodyne optical communication, and more particularly, to a polarization wave diversity optical receiver utilizing a baseband combining method.

A coherent optical communication method utilizing the amplitude, frequency and phase, etc., of a light carrier having a high coherency to provide an optimum optical communication, has become widely used.

A problem arising when realizing such a coherent optical communication method is the fluctuation of the state of the polarization wave, and as a countermeasure thereto, a polarization wave diversity receiving method has been proposed.

In this polarization wave diversity receiving method, two polarized wave components are combined, and accordingly, in this method of combining intermediate frequencies and a method of combining basebands are considered.

The intermediate frequency combining method is a method in which the phases of two polarization wave components are previously made to coincide and are then combined by adding; and the base band combining method is a method in which the two polarization wave components are demodulated and then combined by adding the two components together.

In the intermediate frequency combining method, the matching of the phases is difficult, and thus the realization thereof is difficult, whereas, in the baseband combining method, although two detection circuits are necessary, the realization thereof is easy.

(2) Description of the Related Art

In a conventional coherent optical communication system, a polarization wave diversity receiving system is preferably employed to overcome the signal fading caused by the fluctuation of the state of the polarization wave. To realize the polarization wave diversity receiving system, the above-mentioned baseband combining method is conventionaly and preferably employed. In the conventional baseband combined method, two polarized components of intermediate frequency signals are simply combined and the combined signal is fed back to control a local oscillating circuit.

Since the phases of the intermediate frequency signals, however, do not always match each other, the power of the combined signal may often become zero.

If the power of the combined signal becomes zero, control of the local oscillating circuit is impossible. So, in the conventional baseband combining system, the stabilization of the intermediate frequency cannot always be guaranteed.

SUMMARY OF THE INVENTION

The present invention, solves these problems. An object of the present invention is to provide a polarization diversity optical receiver for coherent optical communication in which a baseband combining method is utilized and an intermediate frequency signal for stabilizing an optical local oscillating circuit can be obtained regardless of the phase difference and the amplitude ratio of the optical detected signals.

To attain the above object, there is provided, according to the present invention, a polarized wave diversity optical receiver for coherent optical communication comprising: an optical local oscillating circuit for oscillating local oscillating light; a mixing circuit for receiving signal light transmitted through an optical fiber and the local oscillating light from the optical local oscillating circuit, and for obtaining two polarized components; a detecting circuit for detecting the signals of the respective polarized components from the mixing circuit to output intermediate frequency signals; and a frequency control circuit for controlling, in accordance with the intermediate frequency signals of the respective polarized components from the detecting circuit, the oscillating frequency of the optical local oscillating circuit. The frequency control circuit comprises means for obtaining an output signal which is a combined signal of a sum and a difference of the intermediate frequency signals.

In place of the frequency control circuit, in the above-mentioned polarized wave diversity optical receiver, there may be provided, according to another aspect of the present invention, local oscillating optical phase modulating means for modulating either one of the polarized components of the local oscillating light from the optical local oscillating circuit.

In place of the frequency control circuit in the above-mentioned polarized optical receiver, there may also be provided, according to still another aspect of the present invention, detected output signal modulating means for modulating either one

of the detected outputs of the respective polarized wave components from the detecting circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram showing a conventional coherent light communication system;

Fig. 2 is a block diagram showing an example of a conventional coherent light communication polarization diversity light receiver;

Figs. 3A to 3C are waveform diagrams explaining the function of the unit shown in Fig 2;

Figs. 4 to 7 are principal block diagrams of the present invention;

Fig. 8 is a block diagram showing a first embodi ment of the present invention;

Figs. 9A to 9D and Figs. 10A to 10D are waveform diagrams for explaining the function of the first embodiment of the present invention;

Fig. 11 is a block diagram showing a second embodiment of the present invention;

Fig. 12 is a block diagram showing a third embodiment of the present invention;

Fig. 13 is a block diagram showing a fourth embodiment of the present invention;

Fig. 14 is a block diagram showing a fifth embodiment of the present invention;

Fig. 15 is a block diagram showing a sixth embodiment of the present invention;

Fig. 16 is a block diagram showing a seventh embodiment of the present invention;

Fig. 17 is a block diagram showing an eighth embodiment of the present invention;

Fig. 18 is a block diagram showing a ninth embodiment of the present invention;

Fig. 19 is a block diagram showing a tenth embodiment of the present invention; and

Fig. 20 is a block diagram showing a modification of the first embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For better understanding of the present invention, conventional coherent optical communication will first be described with reference to Figs. 1, 2, and 3A and 3C.

Figure 1 is a block diagram illustrating a conventional coherent optical communication system. In Fig. 1, 1′ is a transmitter having a light source (LS) 2, an optical modulation circuit (MOD) 3, and a light source stabilizing unit (STAB) 4.

A semiconductor laser, for example, capable of effecting single mode oscillating, is used as the light source 2. When the semiconductor laser is used as mentioned above, the light source stabilizing unit 4 is provided with a temperature control unit for controlling the laser temperature to a constant value.

Further, the optical modulation unit 3 is able to effect FSK (frequency shift keying) modulation, ASK (amplitude shift keying) modulation, and PSK (phase shift keying) or DPSK (differential phase shift keying) modulation of the input signal.

Reference 5′ denotes an optical fiber used as the transmission medium and, for example, is usually a single mode optical fiber.

Reference 6′ denotes a receiver which comprises an optical local oscillating circuit 7, a mixing circuit 8 for mixing the optical signal transmitted through the optical fiber 5 with the local oscillating light from the optical local oscillating circuit 7, a detection circuit 9 for detecting the mixed output of the mixing circuit 8, and a demodulating/discriminating circuit 10 for taking a signal corresponding to the above-mentioned input signal from the detected output of the detecting circuit 9.

A semiconductor laser is also used as the optical local oscillating circuit 7, and the optical local oscillating circuit 7 is also maintained at a constant temperature by a temperature control circuit, so that the unit is stabilized.

In principle, this construction allows a coherent optical communication to be conducted. A problem arising when realizing such a coherent optical communication is the above-mentioned fluctuation of the polarized state, and preferably, a polarization diversity receiving system is employed as a countermeasure thereto.

Further, when realizing the polarization diversity receiving system, preferably the baseband combining method is utilized as mentioned before.

Figure 2 is a block diagram of the polarization diversity optical receiver in which the polarization diversity optical receiving method utilizing the baseband combining method is used.

In Fig. 2, 6 denotes a polarization diversity optical receiver comprising an optical local oscillating circuit 7 for oscillating a local oscillating light, a mixing circuit 8 for mixing the two types of polarized components of the signal light transmitted through an optical fiber 5′ with the local oscillation light from the optical local oscillating circuit 7, a detecting circuit 9 for detecting the signals of the respective polarized components from the mixing circuit 8, a demodulating-adding-discriminating circuit 10 for taking out the signals corresponding to the transmitted input signal from the detected output of the detecting circuit 9, and an automatic frequency control circuit 11 for controlling oscillating signals of the local oscillating circuit 7 in accordance with the intermediate frequency signals e_P

and e_S of the respective polarized components from the detecting circuit 9.

The automatic frequency control circuit 11 comprises an adding circuit 11A for adding the intermediate frequency signals (detected signals) e_S and e_P of the respective polarized components from the detected circuit 9, and a control circuit 11B for controlling the oscillating frequency of the optical local oscillating circuit 7 in accordance with the output of the adding circuit 11A.

The control circuit 11B comprises a frequency discriminating circuit for discriminating the frequency of the signal obtained by the adding circuit 11A, to output the corresponding voltage signal, and a drive circuit for converting the output of the frequency discriminating circuit into an electric current signal and input same to an oscillating frequency control input end of the optical local oscillating circuit 7.

The intermediate frequency is stabilized by feeding back the detected output information as shown above.

In a conventional polarization diversity optical receiver utilizing the baseband combining method as shown in Fig. 2, however, the phases of the two intermediate frequency signals e_S and e_P are not matched, and therefor, if added as they are, the control signal (the intermediate frequency signal for the AFC) applied to the optical local oscillating circuit 7 may be, in some cases, zero, so that the frequency discriminating circuit will not operate.

Namely, when a heterodyne-type coherent optical communication system of FSK (or ASK) is considered, the above-mentioned detected outputs (intermediate frequency signals) e_S and e_P can be expressed as follows.

$e_P = (a)^{1/2}S(t)\cos(wt)$ (1)

$e_S = (1-a)^{1/2}S(t)\cos(wt+\theta)$ (2)

wherein a = (signal emitted light power)/(total signal emitted power), $S(t) = S_0 m(t)$ where $m(t) = 0$ (in case of space) and $m(t) = 1$ (in case of mark), and θ is a phase difference due to polarization.

When both are combined as they are, the output signal e(t) is

$e(t) = e_P(t) + e_S(t)$

$= S(t)\{(a)^{1/2}\cos(wt) + (1-a)^{1/2}\cos(wt+\theta)\}$ (3)

When the worst case ($a = 1/2$, $\theta = \pi$) is considered, $e(t) = 0$ will be obtained, and accordingly, the intermediate frequency signal for the AFC can not be obtained.

This situation is illustrated in Figs. 3A to 3C.

Figures 3A and 3B are examples of the waveforms of the intermediate frequencies e_S and e_P, respectively, and Fig. 3C is an example of the combined waveform.

Next, when a heterodyne-type coherent optical communication system having PSK (or DPSK: differential phase shift keying) is considered, the above-mentioned detected outputs (intermediate frequency signals) e_S and e_P can be expressed as follows.

$e_P = (a)^{1/2}S_0\cos(wt+\phi(t))$ (4)

$e_S = (1-a)^{1/2}S_0\cos(wt+\phi(t)+\theta$ (5)

wherein $\phi(t)$ is $\pi m(t)$ (wherein $m(t) = 0$ (in case of space) or 1 (in case of mark)), and when both are combined as they are, the output signal e(t) is

$e(t) = e_P(t) + \ell_S(t)$

$= S_0\{(a)^{1/2}\cos(wt+\phi(t)) + (1-a)^{1/2}\cos(wt+\phi(t)+\theta)\}$ (6)

When the worst case ($a = 1/2$, $\theta = \pi$) is considered, $e(t) = 0$ will be obtained, and accordingly, the intermediate frequency signal for the AFC cannot be obtained, as in the case of the heterodyne type coherent optical communication system having FSK (or ASK).

Figure 4 to 7 are principal block diagram of the present invention. A polarization diversity optical receiver 6 shown in Fig. 4 comprises an optical local oscillating circuit 7, a mixing circuit 8, a detecting circuit 9, a demodulating-adding-discriminating circuit 10, and an automatic frequency control circuit 11.

The optical local oscillating circuit 7 is used for oscillating a local oscillating light; the optical mixing circuit 8 is used for mixing the two types of polarized components of the signal light transmitted through the optical fiber 5 with the local oscillating light from the optical local oscillating circuit 7; the detecting circuit 9 is used for detecting the signals of the polarized components from the mixing circuit 8; and the demodulating-adding-discriminating circuit 10 is used for taking out a signal corresponding to the transmitted input signal from the detected output of the detecting circuit 9.

Further, the automatic frequency control circuit 11 is used for controlling the oscillating frequency of the optical local oscillating circuit 7 in accordance with the intermediate frequency signals e_S and e_P of respective polarized components from the detecting circuit 9. The automatic frequency control circuit 11 comprises a first adder 111 for taking a sum of the intermediate frequency signals e_S and e_P, a subtracter 112 for taking a difference of the intermediate frequency signals e_S and e_P, a first frequency discriminating circuit 113 for discriminating a frequency with respect to the outputs from the first adder 111, a second frequency discriminating circuit 114 for discriminating a frequency with respect to the outputs from the subtracter 112, and a second adder 115 for adding the output from the first frequency discriminator 113 and the output from the second frequency discriminating 114, as well as power dividers 116 and 117 for inputting the intermediate frequency signals of the respective polarized components from the detecting circuit 9 to the first adder 111 and the sub-

tracter 112, and automatic gain control circuits 118 and 119 for adjusting the output gain from the first adder 111 and the subtracter 112.

Further, the automatic frequency control circuit 11 comprises a driver circuit 120 for converting the output of the second adder 115 to an electric current signal and inputting same to the oscillating frequency control input end of the optical local oscillating circuit 120.

The polarization diversity optical receiver 6 shown in Fig. 5 comprises an optical local oscillating circuit 7, a mixing circuit 8, a detecting circuit 9, a demodulating-adding-discriminating circuit 10, an automatic frequency control circuit 11, and a local oscillating optical phase modulation means 13. The mixing circuit 8 and the automatic frequency control circuit 11 of the polarization diversity optical receiver 6 shown in Fig. 5 are different from those of the polarization diversity optical receiver shown in Fig. 4. Namely, the mixing circuit 8 in Fig. 5 is used for dividing the signal light transmitted through the optical fiber 5 and the local oscillating light from the optical local oscillating circuit 7 into two types of polarized components respectively, and for mixing the respective polarized components. A local oscillating optical phase modulation means 13 is provided in the mixing circuit 8, and is used for modulating the phase of one of the polarized components divided from the local oscillating light from the optical local oscillating circuit 7. Note that this includes shifting the phase of one of the divided polarized components with respect to the phase of the other polarized components.

Note that the automatic frequency control circuit 11 is provided, as in Fig. 2, with the adding circuit 11A and the control circuit 11B.

The polarization diversity optical receiver 6 shown in Fig. 6 also comprises an optical local oscillating circuit 7, a mixing circuit 9, a demodulating-adding-discriminating circuit 10, an automatic frequency control circuit 11, and a local oscillating optical phase modulating means. The local oscillating optical phase modulating means is provided in the optical local oscillating circuit 7. Namely, the optical local oscillating circuit 7 in Fig. 6 comprises two semiconductor lasers 71 and 72 for outputting local oscillating lights having different polarization states to each other, and further, it is so constructed that the output phase of one of these semiconductor lasers 71 and 72 is modulated or one output frequency is shifted by a predetermined amount with respect to the other output frequency. Accordingly, in the local oscillating lights from the optical local oscillating circuit 7, the phase of one of the polarized components is modulated or the frequency of one polarized component is shifted by a predetermined amount with respect to the frequency of the other polarized component.

Further, the polarization diversity optical receiver 6 shown in Fig. 7 comprises an optical local oscillating circuit 7, a mixing circuit 8, a detecting circuit 9, a demodulating-adding-discriminating circuit 10, an automatic frequency control circuit 11, and a phase modulation means 14. The local oscillating optical phase modulating means 14 is used for modulating the phase of either of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9. Note that this includes that for shifting the frequency of one of the detected outputs by a predetermined amount with respect to the frequency of the other detected output.

Further, the phase modulating means 14 may be replaced by a time delay circuit for delaying one of the detected outputs by a predetermined time with respect to the other detected output.

In Figs. 4 to 7, the same symbols represent substantially the same or similar parts.

Due to the above construction of the polarization diversity optical receiver 6 shown in Fig. 4, when the intermediate frequency signals e_S and e_P are fed back, the sum of these intermediate frequency signals e_S and e_P is output from the adder 111 and the difference between these intermediate frequency signals e_S and e_P is output from the subtracter 112. Then, with respect to these sum signal $e_S + e_P$ and the difference signal $e_S - e_P$, the frequencies are discriminated by the frequency discriminating circuit 113 and 114, respectively, and further, the outputs after the frequency discrimination are added and combined.

Accordingly, neither the sum nor the difference of the intermediate frequency signals e_S and e_P is made zero, and thus the combined signal is not made zero. Therefore, at least one of the frequency discriminating circuits can be operated, and thus the intermediate frequency signal for stabilizing the optical local frequency oscillating circuit can be always obtained.

Also, in the polarization diversity optical receiver 6 shown in Fig. 5, the local oscillation optical phase modulating means 13 modulates one of the divided polarized components of the local oscillating light from the optical local oscillating circuit 7. Accordingly, the interrelationship between the detected output signals is reduced, and thus the combined signal is not made zero, resulting in a stabilization of the intermediate frequency.

Further, in the polarization diversity optical receiver 6 shown in Fig. 6, the local oscillating lights from the two semiconductor lasers 71 and 72 in the optical local oscillating circuit 7 have a different polarized states, and one of the output phases of the semiconductor lasers 71 and 72 is modulated, or one of the output frequency is shifted by a

predetermined amount with respect to the other of the output frequency. Therefore, it is possible to modulate one of the phases of the polarized components of the local oscillating light from the optical local oscillating circuit 7 or to shift the frequency of one of the polarized components with respect to the frequency of the other polarized component by a predetermined amount, so that the interrelationship between both detected output signals is also reduced and the combined signal is not made zero, enabling a similar stabilization of the intermediate frequency.

Still further, in the polarization diversity optical receiver 6 shown in Fig. 7, since a phase modulation of either of the phases of the detected outputs e_S and e_P of the respective polarization components from the detection circuit 9 can be effected, the interrelationship between the output detected signals is reduced and the combined signal is not made zero, enabling a similar stabilization of the intermediate frequency. The same effects can be obtained when a frequency modulation or a delay is effected on either of the detected outputs e_S and e_P.

Embodiments of the present invention will be described as follows, with reference to the drawings.

(a) Description of the First Embodiment

Figure 8 is a block diagram showing the first embodiment, and illustrates a heterodyne-type coherent optical communication system having FSK (or ASK).

As shown in Fig. 8, 6 denotes a polarization diversity optical receiver as a receiver. The polarization diversity optical receiver 6 comprises an automatic frequency control circuit 11 in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the decoding-adding-discriminating circuit 10.

The optical local oscillating circuit 7 is used for oscillating local oscillating light $P_{\ell 0}$, and uses semiconductor lasers. The laser temperature is maintained at a constant value by a light source stabilizing unit 18 operating as a temperature control unit.

The mixing circuit 8 is used for mixing the two polarized components of the signal light Psi transmitted through the optical fiber 5 with the local oscillating light $P_{\ell 0}$ form the optical local oscillating circuit 7, respectively, and comprises a polarized wave separation optical fiber coupler 19 for separating the waves of the signal light Psi from the optical fiber 5 and the local oscillating light $P_{\ell 0}$ from the optical local oscillating circuit 7, and a polarization maintaining optical fiber coupler 20 for maintaining the polarized state.

The power distribution to the P polarized component of the signal light Psi is aPsi, and the power distribution to the S polarized component of the signal light Psi is (1-a) Psi; the power distribution to the P polarized component of the local oscillating light $P_{\ell 0}$ is 1/2 $P_{\ell 0}$, and the power distribution to the S polarized component of the local oscillating light signal light $P_{\ell 0}$ is 1/2 $P_{\ell 0}$.

Note that a represents (signal emitting light power)/(total signal emitting light power of the P polarized component).

The detecting circuit 9 is used for detecting the signals of the respective polarized components from the mixing circuit 3, and comprises light-electricity converting circuits 21P and 21S, which are constructed as double-balanced optical receivers, post amplifiers 22P and 22S, and bandpass filters 23P and 23S.

The light electricity converting circuits 21P and 21S receive light signals and converting same into electric signals; the post amplifiers 22P and 22S amplify the electric outputs from the light-electricity converting circuits 21P and 21S; and the bandpass filters 23P and 23S filter only a desired frequency band and output the intermediate frequency signals e_S and e_P.

The demodulating-adding-discriminating circuit 10 is provided with a demodulating function for taking out a signal corresponding to the signal transmitted from the detected outputs (intermediate frequency signals) e_S and e_P of the detection circuit 9, and comprises delay detection circuits 24P and 24S, an adding circuit 25, and a discriminating circuit 27.

The delay detecting circuits 24P and 24S comprise delay circuits 24P-1 and 24S-1 and the delay times in the respective delay circuit 24P-1 and 24S-1 are set to be nearly in the case of FSK (ASK).

The adding circuit 25 is used for combining by adding the outputs Vp and Vs of the respective delay detecting circuits 24P and 24S.

The low pass filter 26 is used for eliminating unnecessary band noise, and the discriminating circuit 27 is used for discriminating "0" and "1" data from the signal, to take out a signal corresponding to the transmitted input signal. Note that the discrimi nating circuit 27 is able to extract timing signals for discriminating "0" and "1" from the input signals.

The automatic frequency control circuit 11 is used for controlling the oscillating frequency of the optical local oscillating circuit 7 based on the intermediate frequency signals e_S and e_P of respective polarized components from the detecting circuit 9. The automatic frequency control circuit 11 comprises a first adder 111 for taking a sum of the

intermediate frequency signals e_S and e_P, a subtracter 112 for taking a difference of the intermediate frequency signals e_S and e_P, a first frequency discriminating circuit 113 for discriminating a frequency with respect to the outputs from the first adder 111, a second frequency discriminating circuit 114 for discriminating a frequency with respect to the outputs from the subtracter 112, and a second adder 115 for adding the output from the first frequency discriminating 113 and the output from the second frequency discriminator 114, as well as power dividers 116 and 117 for inputting the intermediate frequency signals of the respective polarized components from the detecting circuit 9 to the first adder 111 and the subtracter 112, and automatic gain control circuits 118 and 119 for adjusting the output gain from the first adder 111 and the subtracter 112.

The automatic frequency control circuit 11 further comprises a drive circuit 120 for converting the output of the second adder 115 to an electric current signal and inputting same to the oscillating frequency control input end of the optical local oscillating circuit 120.

In Fig. 8, semiconductor lasers for example, by which single mode oscillations are possible, are used as the light source 2. Also, as the light source stabilizing unit 4, a unit having, for example, a temperature control unit for controlling the tempera tures of the lasers to a constant value, is used.

Further, the amplifier 28 is used for amplifying the input signal (data) and supplying the current signal 1_{AC} to the oscillating frequency control end of the light source 2. A bias current 1_{DC} is also supplied to the oscillating frequency control end of the light source 2.

And accordingly, the optical modulation is carried out so that the ASK modulation (pulse amplitude modulation) or FSK modulation (pulse frequency modulation) can be effected.

Also, in Fig. 8, reference 5 denotes the optical fiber used as a transmission medium.

According to the above constitution, when the intermediate frequency signals e_S and e_P are fed back, the power of the intermediate frequency signals e_S and e_P is divided into two parts which are input respectively to the first adder 111 and the subtracter 112, and then the sum data of the intermediate frequency signals e_S and e_P is output from the first adder 111 and the difference data of the intermediate frequency signals e_S and e_P is output from the subtracter 112. Then the output gain is adjusted by the AGC circuits 118 and 119. Subsequently, with respect to the sum data $e_S + e_P$ and difference data $e_S - e_P$, the frequencies are discriminated by the frequency discriminating circuits 113 and 114, the respective outputs after the discrimination are added and combined by the second adder 115, and the thus-added and combined intermediate signal is input through the drive circuit 120 to the control input end of the optical local oscillating circuit 7.

Accordingly, the sum and the difference of the intermediate frequency signals e_S and e_P are not made zero, and thus the combined signal is not made zero.

Namely, as shown in Figs. 9A and 9B, when the phase difference of the intermediate frequency signals e_S and e_P is zero, the difference of the intermediate frequency signals e_S and e_P is made zero as shown in Fig. 9C, but the sum of the intermediate frequency signals e_S and e_P is not made zero as shown in Fig. 9D. Also, when the phase difference of the intermediate frequency signals e_S and e_P is π, as shown in Figs. 10A and 10B, the sum of the intermediate frequency signals e_S and e_P is made zero as shown in Fig. 10C, but the difference of the intermediate frequency signals e_S and e_P is not made zero, as shown in Fig. 10D. Therefore, either of the frequency discriminating circuits 114 and 113 can be operated, and thus the intermediate frequency signal for stabilizing the optical local oscillating circuit can be always obtained.

Note that the gain adjusting ability of the AGC circuits 118 and 119 may be three times the gain adjusting ability usually available under an average power supply, when the mark ratio m = 1/2. This value is usually sufficient in a standard AGC circuit.

Accordingly, an intermediate frequency signal having a desired frequency is obtained and the desired gain can be held, and thus the desired stabilization of the oscillating frequency (intermediate frequency) of the optical local oscillating circuit 7 can be realized.

(b) Description of the Second Embodiment

Figure 11 shows a block diagram of the second embodiment of the present invention, and illustrates a heterodyne type coherent optical communication system having FSK (or ASK).

As shown in Fig. 11, the polarization diversity optical receiver 6 also comprises an automatic frequency control circuit 11 in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the decoding-adding-discriminating circuit 10. The constitutions and the functions of the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the decoding-adding-discriminating circuit 10 are the same as those of the first embodiment, and therefore, a detailed description thereof will be omitted.

In this second embodiment, the constitution of the automatic frequency control circuit 11 is different from that of the first embodiment. Therefore,

the constitution of the automatic frequency control circuit 11 is described as follows.

Namely, the automatic frequency control circuit 11 comprises a first adder 111 for taking a sum of the intermediate frequency signals e_S and e_P , a subtracter 112 for taking a difference of the intermediate frequency signals e_S and e_P , a first frequency discriminating circuit 113 for discriminating a frequency with respect to the outputs from the first adder 111, a second frequency discriminating circuit 114 for discriminating a frequency with respect to the outputs from the subtracter 112, and a second adder 115 for adding the output from the first frequency discriminator 113 and the output from the second frequency discriminator 114, as well as power dividers 116 and 117 for inputting the intermediate frequency signals of the respective polarized components from the detecting circuit 9 to the first adder 111 and the subtracter 112, and automatic gain control circuits 118 and 119 for adjusting the output gain from the first adder 111 and the subtracter 112, and is further provided with a delay circuit 121 for delaying either of the intermediate frequency signals e_S and e_P of the respective polarized components from the bandpass filters 23P and 23S by, for example, one bit, before inputting same to the first adder 111 and the subtracter 112.

As in the first embodiment, the automatic frequency control circuit 11 comprises a driver circuit 120 for converting the output of the second adder 115 to an electric current signal and for inputting same to the oscillating frequency control input end of the optical local oscillating circuit 120.

In the above constitution, when the intermediate frequency signals e_S and e_P are fed back, one of the intermediate frequency signals e_S and e_P i.e., e_S , is delayed, and the power of the delayed intermediate frequency signal e_S and non-delayed intermediate frequency signal e_P are respectively divided by the power dividers 16 and 117 and input to the first adder 111 and the subtracter 112, respectively. Subsequently, the sum data of the intermediate frequency signals e_S and e_P output from the first adder 111 and the difference data of the intermediate frequency signals e_S and e_P , is output from the subtracter 112, and then the output gain is adjusted by the AGC circuits 118 and 119. Then the frequencies of these sum signals $e_S + e_P$ and the difference signal $e_S - e_P$ are discriminating by the frequency discriminating circuits 113 and 114. The respective outputs after the frequency discrimination are added and combined by the second adder 115, and the adder and combined intermediate frequency signal is input through a drive circuit 120 to the control input end of the optical local oscillating circuit 7.

Accordingly, the interrelationship between the intermediate frequency signals e_S and e_P can be further reduced than in the first embodiment, and therefore, the sum and the difference of the intermediate frequency signals e_S and e_P are not made zero, and as a result, the combined signal is not made zero.

Accordingly, in this case also, since either of the frequency discriminating circuits 114 and 113 can be operated, the intermediate frequency signal for stabilizing the optical local oscillating circuit can be always obtained.

Note that the gain adjusting ability of the AGC circuits 118 and 119 also is sufficient for a standard AGC circuit as in the first embodiment, and thus an intermediate frequency signal having a desired frequency can be always obtained and the desired gain can be held, whereby a required stabilization of the oscillating frequency (intermediate frequency) of the optical local oscillating circuit 7 can be obtained.

(c) Description of the Third Embodiment

Figure 12 is a block diagram showing a third embodiment of the present invention, and illustrates a heterodyne-type coherent optical communication system having DPSK.

As shown in Fig. 12, 6 denotes a polarization diversity optical receiver which comprises an automatic frequency control circuit 11, in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the demodulating-adding-discriminating circuit 10.

In this third embodiment, the constitution of the automatic frequency control circuit 11 corresponds to that of the first embodiment, except for one portion thereof. Therefore, the constitution of the automatic frequency control circuit 11 will be described as follows.

Namely, the automatic frequency control circuit 11 comprises, as in the first embodiment, a first adder 111 for taking a sum of the intermediate frequency signals e_S and e_P , a subtracter 112 for taking a difference of the intermediate frequency signals e_S and e_P , a first frequency discrimination circuit 113 for discriminating a frequency of the outputs from the first adder 111, a second frequency discriminating circuit 114 for discriminating a frequency of the outputs from the subtracter 112, and a second adder 115 for adding the output from the first frequency discriminator 113 and the output from the second frequency discriminator 114, as well as power dividers 116 and 117 for inputting the intermediate frequency signals of the respective polarized components from the detecting circuit 9 to the first adder 111 and the subtracter 112, and AGC circuits 118 and 119 for adjusting the

output gains from the first adder 111 and the subtracter 112. But different from the first embodiment, the automatic frequency control circuit 11 comprises doublers 122 and 123 for doubling the respective output frequencies before the addition and the subtraction.

As mentioned above, the difference between the automatic frequency control circuit 11 of the first embodiment resides in the provision of the doublers, by which the expansion of the spectrum due to the phase information of the intermediate frequencies can be cancelled. Namely, the modulated signal is cancelled and only the doubled frequency components of the intermediate frequency signals are output.

Note that, as in the first embodiment, the automatic frequency control circuit 11 comprises a driver circuit 120 for converting the output of the second adder 115 to an electric current signal and inputting same to the oscillating frequency control input end of the optical local oscillating circuit 120.

Also, the delay times in the delay circuits 24P-1 and 24S-1 in the delay detecting circuits 24P and 24S are set, in the case of DPSK, to one bit.

Note that, in Fig. 12, 1 denotes a transmitter for DPSK. The transmitter 1 comprises a light source 2, an optical modulation circuit 3, a light source stabilizing circuit 30, an amplifier 31, a differential coding circuit 32, and a crystal oscillator 33.

As the light source 2, for example, semiconductor lasers capable of single mode oscillation are used. When the semiconductor lasers are used as mentioned above, a unit having, for example, a temperature control unit for controlling the temperature of the lasers, is used.

Further, the differential coding circuit 32 is used for receiving a reference signal from the crystal oscillator 33 and input signal (data) and for a differential coding of an output. The output of the differential coding circuit 32 is input through the amplifier 31 and the waveform shaping circuit 30 to the optical modulation circuit 3.

Accordingly, optical modulation is carried out so that DPSK modulation of the input signal can be effected.

Note that 5 denotes an optical fiber as a transmitting medium.

In the above constitution, when the intermediate frequency signals e_P and e_S are fed back, the expansion of the spectrum due to the phase information of the intermediate frequency signals is cancelled in the doublers 122 and 123, and the power of the intermediate frequency signals e_P and e_S is divided into two parts by the power dividers 116 and 117, and input respectively to the first adder 111 and the subtracter 112. Subsequently, the sum data of the intermediate frequency signals e_P and e_S is output from the first adder 111 and the difference data of the intermediate frequency signals e_P and e_S is output from the output of the subtracter 112. Then, the output gains of these sum signal $e_S + e_P$ and difference signal $e_S - e_P$ are adjusted in the AGC circuits 118 and 119, and subsequently the frequencies of these sum signal $e_S + e_P$ and difference signal $e_S - e_P$ are discriminated by the frequency discriminating circuits 113 and 114. The respective outputs after the frequency discriminations are added and combined, and the added and combined intermediate frequency signals are input through the driving circuit 120 to the control input end of the optical local oscillating circuit 7.

Accordingly, as in the first embodiment, the interrelationship between the intermediate frequency signals e_S and e_P can be reduced, and therefore, the sum and the difference of the intermediate frequency signals e_S and e_P are not made zero, and as a result, the combined signal is not made zero.

Accordingly, in this case also, since either of the frequency discriminating circuits 114 and 113 can be operated, the intermediate frequency signal for stabilizing the optical local oscillating circuit can be always obtained.

Note that the gain adjusting ability of the AGC circuits 118 and 119 is sufficient for a standard AGC circuit as in the first and the second embodiments, and thus an intermediate frequency signal having a desired frequency can be always obtained, and further, the desired gain can be held, so that the required stabilization of the oscillating frequency (intermediate frequency) of the optical local oscillating circuit 7 can be obtained, as in the first and second embodiments.

(d) Description of the Fourth Embodiment

Figure 13 is a block diagram showing a third embodiment of the present invention, and illustrates a heterodyne-type coherent optical communication system having DPSK.

The polarization diversity optical receiver 6 in Fig. 13 also comprises an automatic frequency control circuit 11, in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the decoding-adding-discriminating circuit 10.

The optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the decoding-adding-discriminating circuit 10 are the same as those of the first, second, and third embodiments, and therefore, a detailed description thereof is omitted.

In the fourth embodiment, the constitution of the automatic frequency control circuit 11 corre-

sponds to that of the second embodiment, except that it comprises doublers 122 and 123. The portion different from that in the above-mentioned third embodiment comprises a delay circuit for delaying one of the intermediate frequency signals e_P and e_S of the respective polarized components from the bandpass filters 23P and 23S by, for example, one bit, before inputting same to the first adder 111 and the subtracter 112.

Therefore, according to this fourth embodiment, the interrelationship between the intermediate frequency signals e_P and e_S can be further reduced than in the third embodiment, and thus the sum and the difference of the intermediate frequency signals e_P and e_S are not made zero, and therefore, the combined signal is not made zero. As a result, either of the frequency discriminating circuits 114 and 113 can be operated, and accordingly, the intermediate frequency signal for stabilizing the optical local oscillating circuit can be always obtained.

The gain adjusting ability of the AGC circuits 118 and 119 is also sufficient for a standard AGC circuit as in the first to third embodiments, and thus an intermediate frequency signal having a desired frequency can be always obtained, and therefore, the required stabilization of the oscillating frequency (intermediate frequency) of the optical local oscillating circuit 7 can be obtained.

(e) Description of the Fifth Embodiment

Figure 14 is a block diagram showing a fifth embodiment of the present invention, and illustrates a heterodyne-type coherent optical communication system having FSK (or ASK).

The polarization diversity optical receiver 6 shown in Fig. 14 comprises, in addition to the optical local oscillating circuit 7, a mixing circuit 8, a detecting circuit 9, and a demodulating-adding-discriminating circuit 10, an adding circuit 11A and a control circuit 11B, which constitute an automatic frequency control circuit, and a local oscillating optical phase modulating means 13.

The optical local oscillating circuit 7 provided with the light source stabilizing unit 18, the detecting circuit 9, and the demodulating-adding-discriminating circuit 10 is the same as in the first to fourth embodiments.

The mixing circuit 8 is used for mixing the two polarized components of the signal light Psi transmitted through the optical fiber 5 with the local oscillating light $P_{\ell 0}$ from the optical local oscillating circuit 7, respectively, and comprises a polarization wave separation optical fiber coupler 19 for separating the waves of the signal light Psi from the optical fiber 5 and the local oscillating light $P_{\ell 0}$ from the optical local oscillating circuit 7, and a polarization maintaining optical fiber coupler 20 for maintaining the polarized state.

The power distribution to the P polarized component of the signal light Psi is aPsi, and the power distribution to the S polarized component of the signal light Psi is (1-a) Psi; the power distribution to the P polarized component of the local oscillating light $P_{\ell 0}$ is 1/2 $P_{\ell 0}$, and the power distribution to the S polarized component of the local oscillating light signal light $P_{\ell 0}$ is 1/2 $P_{\ell 0}$.

Note that a denotes (signal emitting light power)/(total signal emitting light power of the P polarized component).

The local oscillating optical phase modulation means 13 is used for modulating the phase of the polarized component of the local oscillating light from the optical local oscillating circuit 7, and to this end, comprises an oscillator 131 and a phase modulator 132 for modulating the phase of the polarized component (light signal) of the local oscillating light from the optical local oscillating circuit 7, by using the signal from the oscillator 131.

The adding circuit 11A is used for adding the detected outputs e_S and e_P of the respective polarized components from the bandpass filters 23P and 23S, and to this end, comprises an adder 111′. The adding circuit 11 comprises an automatic gain control circuit (AGC circuit) 15 for adjusting the output gain after the addition in the adder 111′.

Further, the control circuit 11B is used for controlling the oscillating frequency of the optical local oscillating circuit 7 based on the output from the adding circuit 11A. To this end, the control circuit 11B is constructed as an automatic frequency control circuit (AFC circuit) comprising a frequency discriminating circuit 16 for discriminating the frequency of the signal obtained by the adding circuit 11A, to output the corresponding voltage output, and a drive circuit 17 for converting the output of the frequency discriminating circuit 16 into a current signal and inputting same to the oscillating frequency control input end of the optical local oscillating circuit 7.

In the above construction, in the polarization diversity optical receiver 6 of this fifth embodiment, the phase of the split polarized component of the local oscillating light from the optical local oscillating circuit 7 is modulated by the local oscillating optical phase modulating means 13, and accordingly, the phase difference between the detected output signals e_S and e_P can be changed from zero to 2π as a function of time. As a result, the interrelationship between the detected output signals e_S and e_P can be reduced, and therefore, the combined signal is not made zero, and thus a desired intermediate frequency can be obtained for the AFC.

Note that the output gain after the addition is adjusted by the automatic gain control circuit (AGC circuit) 14. Preferably, the gain adjusting ability of the AGC circuit 15 is set to cover, for example, a threefold gain adjustment of the average power. When the mark ratio m = 1/2, the threefold gain adjustment of the average power can be made by a standard AGC circuit 15.

Accordingly, an intermediate frequency signal having a desired frequency is obtained and the desired gain can be held, and thus the required stabilization of the oscillating frequency (intermediate frequency) of the optical local oscillating circuit 7 can be obtained.

Note that, as the local oscillating optical phase modulating means 13, the means for modulating the phase of the one polarized component (P or S) of the local oscillating light from the optical local oscillating circuit 7, can be replaced by the means for shifting the frequency of the polarized component (P or S) of the local oscillating light from the optical local oscillating circuit 7 by a desired amount with respect to the other polarized component.

(f) Description of the Sixth Embodiment

Figure 15 is a block diagram showing the sixth embodiment of the present invention, and illustrates a heterodyne-type coherent optical communication system having FSK (or ASK).

The polarization diversity optical receiver 6 comprises, in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the demodulating-adding-discriminating circuit 10, an adding circuit 11A and a control circuit 11B, as well as a local oscillating optical phase modulating means for shifting the phase of the polarized component of the local oscillating light with respect to the phase of the other polarized component. The local oscillating optical phase modulation means is provided in the optical local oscillating circuit 7. Namely, the optical oscillating circuit 7 comprises a first semiconductor laser 71 for outputting local oscillating light having the P polarized component, and a second semiconductor laser 72 for outputting local oscillating light having the S polarized component. The difference between the output frequencies of the respective semiconductor lasers 71 and 72 is locked to a desired value of, for example, several mega hertz when the frequency of the semiconductor laser 71 or 72 is on the order of 2×10^4 hertz, by the automatic frequency control circuit (AFC circuit) 34.

The AFC circuit 34 comprises a photo-electric converting circuit 35 constructed as a double-balanced optical receiver, a post amplifier 36, a bandpass filter 37, a frequency discriminating circuit 38, and a driver circuit 39.

The photo-electric converting circuit 35 is used for receiving light signals from the respective semiconductor lasers 71 and 72 and converting same into electric signals; the post amplifier 36 is used for amplifying the electric output from the photoelectric converting circuit 35; the bandpass filter 37 is used for filtering and outputting only a desired frequency band; the frequency discriminating circuit 38 is used for discriminating the signals from the bandpass filter 37 and outputting the corresponding voltage signals; and the drive circuit 39 is used for converting the output of the frequency discriminating circuit 38 and inputting same to the oscillating frequency control input end of the optical local oscillating circuit 72.

Note that the respective semiconductor lasers 71 and 72 are controlled by the light source stabilizing units 18A and 18B, whereby the laser temperature is kept to a constant value.

Also, the mixing circuit 8, the detecting circuit 9, the demodulating-adding-discriminating circuit 10, and the control circuit 11B are the same as in the fifth embodiment, and therefore, a descriptions thereof is omitted. In the above construction, in the polarization diversity optical receiver 6 shown in Fig. 15, since the respective local oscillating lights from the two semiconductor lasers 71 and 72 in the light local oscillating circuit 7 have different polarized states, and further, the frequency difference of the local oscillating lights is shifted by a predetermined amount, the interrelationship between the detected output signals is reduced and thus the combined signal is not made zero, and therefore the intermediate frequency is stabilized.

Further, circuit for shifting the frequency of one output (polarized component P or S) of the semiconductor lasers 71 and 72 by a predetermined amount with respect to the frequency of the other output (polarized component S or P), can be replaced by a circuit for modulating the phase of one output (polarized component P or S) of the semiconductor lasers 71 and 72.

(g) Description of the Seventh Embodiment

Figure 16 is a block diagram showing the seventh embodiment of the present invention, and illustrates a heterodyne type coherent optical communication system having FSK (or ASK).

The polarization diversity optical receiver 6 shown in Fig. 16 comprises, in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, the demodulating-adding-discriminating circuit 10, the adding circuit 11A and the control circuit 11B, as well as a detected output

phase modulating means 14 for modulating the phase of either of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9.

The detected output phase modulating means 14 comprises an oscillator 141 and a phase modulator 142 for modulating, by the signal from the output of the oscillating circuit 141, the phase of one (electric signal) of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9.

The optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the demodulating-adding-discriminating circuit 10, and the control circuit 12 are the same as in the fifth embodiment, and therefore, a detailed description thereof is omitted. Note that the local oscillating optical phase modulating means 13 is not provided in the mixing circuit 8.

In the above construction, in the polarization diversity optical receiver 6, either of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9 is modulated by the detected output phase modulating means 14, and accordingly, the phase difference between, for example, the detected output signals e_S and e_P , can be changed from 0 to π as a function of time. As a result, the interrelationship between the detected output signals e_S and e_P can be reduced and thus the combined signal is not made zero, and therefore, a desired intermediate frequency signal for the AFC can be obtained whereby the stabilization of the intermediate frequency can be obtained in the same way as in the previous embodiments.

Note that, as the detected output phase modulating means 14, the means for modulating the phase of either (e_S or e_P) of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9 can be replaced by a means for shifting the frequency of one (e_S or e_P) of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9 by a desired amount with respect to the frequency of the other polarized component (e_P or e_S).

(h) Description of the English Embodiment

Figure 17 is a block diagram showing the eighth embodiment of the present invention, and illustrates a heterodyne-type coherent optical communication system having DPSK.

As shown in Fig. 17, the polarization diversity optical receiver 6 comprises, in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, the demodulating-adding-discriminating circuit 10, the adding circuit 11A and the control circuit 11B, as well as a local oscillating optical phase modulating means 13.

The optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, the demodulating-adding-discriminating circuit 10, and the control circuit 11B are the same as in the fifth embodiment, and therefore, a detailed description thereof is omitted.

Note that the adding circuit 11A is used for adding the detected outputs e_S and e_P of the respective polarized components from the band-pass filters 23P and 23S, and to this end, comprises an adder 111′. Also, doublers 29P and 29S are provided for doubling the output frequencies before the addition by the adder 111′. The output gains of the doublers 29P and 29S are adjusted by the automatic gain control circuit (AGC circuit) 15.

The difference from the fifth embodiment shown in Fig. 14 resides in the provision of the doublers 29P and 29S, by which the expansion of the spectrum due to intermediate frequency signal can be cancelled.

In the above construction, in the polarization diversity optical receiver 6 of this eighth embodiment, the phase of the split polarized component of the local oscillating light from the optical local oscillating circuit 7 is modulated by the local oscillating optical phase modulating means 13, and accordingly, the phase difference between, for example, the detected output signals e_S and e_P , can be changed from 0 to π as a function of time. As a result, the interrelationship between the detected output signals e_S and e_P can be reduced, and thus the combined signal is not made zero, whereby a desired intermediate frequency signal for the AFC can be obtained.

Note that the gain of the output in which, by employing the doublers 29P and 29S before the addition, the expansion of the spectrum due to the phase information of the intermediate frequency signals is cancelled, is adjusted by the automatic gain control circuit (AGC circuit) 15. The gain adjusting ability of the AGC circuit 15 is obtained as long as the gain margin of the AGC circuit 15 is 7 dB when the mark ratio is 1/11 (minimum mark ratio) or 10/11 (maximum mark ratio). Such a value is easily realized by the standard AGC circuit 15.

Accordingly, in the eighth embodiment also, an intermediate frequency signal having a desired frequency can be always obtained and a desired gain can be held, and thus the required stabilization of the oscillation frequency (intermediate frequency) of the optical local oscillating circuit 7 can be obtained.

Note that, as the local oscillating optical phase modulating means 13, as in the fifth embodiment, the means for modulating the phase of one polarized component (P or S) of the local oscillating

light from the optical local oscillating circuit 7 can be replaced by a means for shifting the frequency of one polarized component (P or S) of the local oscillating light from the optical local oscillating circuit 7 by a desired amount with respect to the other polarized component.

(i) Description of the Ninth Embodiment

Figure 18 is a block diagram showing the ninth embodiment of the present invention, and illustrates a heterodyne-type coherent optical communication system having PSK or DPSK.

The polarization diversity optical receiver 6 is used for the heterodyne-type coherent optical communication system having DPSK and corresponds to the sixth embodiment shown in Fig. 15. Namely, the polarization diversity optical receiver 6 comprises, in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the demodulating-adding-discriminating circuit 10, the adding circuit 11A to which the outputs from the doublers 29P and 29S are input, and the control circuit 11B, as well as a local oscillating optical phase modulating means for shifting the frequency of one polarized component of the local oscillating light with respect to the frequency of the other polarized component. The local oscillating optical phase modulating means is provided in the optical local oscillating circuit 7.

Namely, the optical local oscillating circuit 7 comprises a first semiconductor laser 71 for outputting a local oscillating light having the P polarized component, and a second semiconductor laser 72 for outputting a local oscillating light having the S polarized component. The frequency difference between the respective semiconductor lasers 71 and 72 is locked to a desired value by an automatic frequency control circuit (AFC circuit) 34. The AFC circuit 34 comprises a photo-electric converting circuit 35 constructed as a double-balance optical receiver, a post amplifier 36, a bandpass filter 37, a frequency discriminating circuit 38, and a drive circuit 39. The photo-electric converting circuit 35, post amplifier 36, bandpass filter 37, frequency discriminating circuit 38, and drive circuit 39 are the same as used in the second embodiment, and therefore, a detailed description thereof is omitted.

In this ninth embodiment also, the respective semiconductor lasers 71 and 72 are controlled by the light source stabilizing units 18A and 18B constructed as temperature control units, so that the laser temperature is kept to a constant value.

Further, the mixing circuit 8, the detecting circuit 9, the demodulating-adding-discriminating circuit 10, the control circuit 11B, and the transmitter 1 (this transmitter 1 comprises a light source 2, an optical modulating circuit 3, a light source stabilizing unit 4, a waveform shaping circuit 30, an amplifier 31, a differential coding circuit 32, and a crystal oscillator 33) are the same as used in the eighth embodiment, and therefore, a detailed description thereof is omitted.

In the above construction, in the polarization diversity optical receiver shown in Fig. 18, the respective local oscillating lights from the two semiconductor lasers 71 and 72 in the optical local oscillating circuit 7 are in the different polarized states, and the frequency difference between the local oscillating lights is shifted by a predetermined amount. Therefore, the interrelationship between the detected output signals is reduced and thus the combined signal is not made zero, and therefore, the required stabilization of the intermediate frequency is obtained as in the previous embodiments.

Note that, in this embodiment also, the means for shifting the phase of one output (polarized components P or S) of the semiconductor lasers 71 and 72 by a desired amount with respect to the phase of the ether output (polarized component S or P) can be replaced by a means for modulating the phase of one output (polarized component P or S) of the semiconductor lasers 71 and 72.

(j) Description of the Tenth Embodiment

Figure 19 is a block diagram showing the tenth embodiment of the present invention and illustrates heterodyne-type coherent optical communication system having PSK.

The polarization diversity optical receiver 6 shown in Fig. 16 is used for the heterodyne-type coherent optical communication system having PSK and corresponds to seventh embodiment. Namely the polarization diversity optical receiver 6 comprises in addition to the optical local oscillating circuit 7, the mixing circuit 8, the detecting circuit 9, and the demodulating-adding-discriminating circuit 10, the adding circuit 11A, to which the outputs from the doublers 29P and 29S are input, and the control circuit 11B, as well as a detected output phase modulation means 14 for modulating either of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9.

The detected outputs phase modulating means 14 comprises an oscillator 141 and a phase modulator 142 for modulating, by the signal from the output of the oscillating circuit 141, the phase of one (electric signal) of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9.

Also, the optical local oscillating circuit 7, the

mixing circuit 8, the detecting circuit 9, the demodulating adding discriminating circuit 10, and the control circuit 12 are the same as used in the eighth embodiment, and therefore, a detailed description thereof is omitted. Note that the local oscillating optical phase modulating means 13 is not provided in the mixing circuit 8.

In the above construction, in the polarization diversity optical receiver 6 shown in Fig. 16, either of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9 is modulated by the detected output phase modulating means 14, and accordingly, the phase difference between, for example, the detected output signals e_S and e_P, can be changed from 0 to π as a function of time. As a result, the interrelationship between the detected output signals e_S and e_P can be reduced and thus the combined signal is not made zero. Accordingly desired intermediate frequency signal for the AFC can be obtained, and thus the required stabilization of the intermediate frequency can be obtained as in the previous embodiments.

Note that, as the detected output phase modulating means 14, the means for modulating the phase of either (e_S and e_P) of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9 can be replaced by a means for shifting the frequency of one (e_S and e_P) of the detected outputs e_S and e_P of the respective polarized components from the detecting circuit 9 by a desired amount with respect to the frequency of the component (e_S and e_P).

Also, the number of bits for the delay by the delay circuit 14 in the automatic frequency control circuit 11 is not restricted to one bit, but may be 1 bit x N (N is usually an integer, but may not be an integer.

Fig. 20 is a block diagram showing a modification of the first embodiment shown in Fig. 8 In Fig. 20, a mixing circuit 8a is different from the mixing circuit 8 in the first embodiment shown in Fig. 8. The other portions are completely the same as those in Fig. 8.

In the mixing circuit 8a, the signal light Psi transmitted through the optical fiber 5 is mixing with the local oscillating light $P_{\ell O}$ from the optical local oscillating circuit 7 by means of a polarized wave maintaining optical fiber coupler 19a, before splitting the signal light into the two polarized comments. After mixing, the mixed signal is split into two polarized components aPsi and (1-a) Psi. Each split and polarized component is further split by a polarized wave splitting optical fiber coupler 19a into two polarized components, one of which is supplied to the photo-electric converter 21P and the other of which supplied to the photo-electric converter 21S. This constitution also provides the same effects as in the first embodiment.

The mixing circuit 8 shown in Figs. 11 to 19 may also be replaced by the mixing circuit 8a shown in Fig. 20, in a similar way as above.

As described above, according to the coherent optical communication polarization diversity optical receiver of the present invention, when utilizing a baseband combining method, the sum and the difference of the intermediate frequency signals of two polarized components are frequency discriminated, and then combined, and therefore, the interrelationship of the intermediate frequency signals is reduced, and thus either of the first and the second frequency discriminating circuits can be operated. Accordingly, the intermediate frequency signal for stabilizing the optical local oscillating circuit can be always obtained, and as a result, an advantage is gained a required stabilization of the intermediate frequency.

Also, according to the coherent optical communication polarization diversity optical receiver of the present invention, when utilizing a baseband combining method, by simply providing a local oscillating optical phase modulating means for modulating the phase of one polarized component of the local oscillating light from the optical local oscillating circuit or a detected output phase modulating means for modulating the phase of either of the detected outputs of the respective polarized components from the detecting circuit, the interrelationship of both intermediate frequency signals is reduced, and thus either of the first and the second frequency discriminating circuits can be operated, and the intermediate frequency signal for stabilizing the optical local oscillating circuit can be always obtained. As a result, an advantage is gained or required stabilization of the intermediate frequency.

Claims

1. A polarized wave diversity optical receiver for coherent optical communication comprising:
an optical local oscillating circuit (7) for oscillating local oscillating light;
a mixing circuit (8) for receiving signal light transmitted through an optical fiber (5) and said local oscillating light from said optical local oscillating circuit (7), to obtain two polarized components;
a detecting circuit (9) for detecting the signals of the respective polarized components from said mixing circuit (8) to output intermediate frequency signals (e_S and e_P); and
a frequency control circuit (11) for controlling, in accordance with the intermediate frequency signals (e_S and e_P) of the respective polarized components from said detecting circuit (9), the oscillating fre-

quency of said optical local oscillating circuit (7); said frequency control circuit (11) comprising means for obtaining an output signal which is a combined signal of a sum and a difference of said intermediate frequency signals (e_S and e_P).

2. A polarized wave diversity optical receiver for coherent optical communication according to claim 1, wherein said frequency control circuit (11) has delay means for delaying either one of said intermediate frequency signals (e_S and e_P), a sum and a difference of the delayed signal delayed by said delay means and the other signal in the two intermediate frequency signals being obtained.

3. A polarized wave diversity optical receiver for coherent optical communication according to claim 1, wherein said frequency control circuit (11) comprises a subtracter (112) for taking a difference between said intermediate frequency signals (e_S and e_P),
a first frequency discriminating circuit (113) for effecting frequency discrimination with respect to the output from said first adder (111),
a second frequency discriminating circuit (114) for effecting frequency discrimination with respect to the output from said subtracter (112), and
a second adder (115) for adding the output from said first frequency discriminating circuit (113) and the output from said second frequency discriminating circuit (114).

4. A polarized wave diversity optical receiver for coherent optical communication according to claim 1, wherein said frequency control circuit (11) comprises a delay circuit (121) for delaying, before inputting into said first adder (111) and said subtracter (112), either of the polarized components of the intermediate frequency signals (e_S and e_P) from said detecting circuit (9).

5. A polarized wave diversity optical receiver for coherent optical communication according to claim 1, wherein said delay circuit (121) is one providing a one-bit delay.

6. A polarized wave diversity optical receiver for coherent optical communication according to claim 3, wherein said frequency control circuit (11) has automatic gain control circuits (118 and 119) for respectively adjusting the output gains of said first adder (111) and said subtracter (112).

7. A polarized wave diversity optical receiver for coherent optical communication according to claim 3, wherein said frequency control circuit (11) comprises power dividers (116 and 117) for inputting the respective polarized components of the intermediate frequency signals from said detecting circuit (9) into said first adder (111) and said subtracter (112).

8. A polarized wave diversity optical receiver for coherent optical communication according to claim 3, wherein said frequency control circuit (11) comprises doublers for doubling the frequencies of the signals before inputting into said adder circuit and said subtracter.

9. A polarized wave diversity optical receiver for coherent optical communication according to claim 8, wherein said frequency control circuit (11) comprises a delay circuit (121) for delaying either of said respective polarized components of the intermediate frequency signals (e_S and e_P) from said detecting circuit (9) before inputting into said first adder (111) and said subtracter (112).

10. A polarized wave diversity optical receiver for coherent optical communication comprising:
an optical local oscillating circuit (7) for oscillating local oscillating light;
a mixing circuit (8) for receiving signal light transmitted through an optical fiber (5) and said local oscillating light from said optical local oscillating circuit (7), and for obtaining two polarized components;
a detecting circuit (9) for detecting the signals of the respective polarized components from said mixing circuit (8) to output intermediate frequency signals (e_S and e_P);
an adding circuit (11A) for adding the respective polarized components of the intermediate frequency signals (e_S and e_P) from said detecting circuit (9);
a control circuit (11B) for controlling said optical local oscillating circuit (7) depending on the added output of said adding circuit (11A); and
local oscillating optical phase modulating means for modulating either one of the polarized components of the local oscillating light from said optical local oscillating circuit (7).

11. A polarized wave diversity optical receiver for coherent optical communication according to claims 1 or 10, wherein said mixing circuit (8) splits the signal light transmitted through said optical fiber (5) and said local oscillating light from said optical local oscillating circuit (7) into two types of polarized components, respectively, and then, mixes the same polarized components to output.

12. A polarized wave diversity optical receiver for coherent optical communication according to claim 11, further comprising wave dividing means (19) for dividing said local oscillating light from said optical local oscillating circuit (7) into two types of polarized components,
said local oscillating optical phase modulating means (13) modulating the phase of either of the polarized components of said local oscillating light from said wave dividing means (19).

13. A polarized wave diversity optical receiver for coherent optical communication according to claim 11, further comprising wave dividing means (19) for dividing said local oscillating light from said optical local oscillating circuit (7) into two types of

polarized components, and said local oscillating optical phase modulating means (13) being one for shifting the frequency of one of the polarized components of said local oscillating light from said wave dividing means (19) by a desired amount with respect to the frequency of the other polarized component.

14. A polarized wave diversity optical receiver for coherent optical communication according to claim 10, wherein said optical local oscillating circuit (7) comprises two semiconductor lasers (71 and 72) for outputting local oscillating lights of different polarized wave components, the output phase or the output frequency of either of the outputs of said semiconductor lasers (71 and 72) being modulated.

15. A polarized wave diversity optical receiver for coherent optical communication according to claim 14, wherein the difference between the output frequencies of said two semiconductor lasers (71 and 72) being locked to a desired value through the frequency control circuit (34).

16. A polarized wave diversity optical receiver for coherent optical communication comprising:
an optical local oscillating circuit (7) for oscillating local oscillating light;
a mixing circuit (8) for receiving signal light transmitted through an optical fiber (5) and said local oscillating light from said optical local oscillating circuit (7), and for obtaining two polarized wave components;
a detecting circuit (9) for detecting the signals of the respective polarized wave components from said mixing circuit (8) to output intermediate frequency signals (e_S and e_P);
an adding circuit (11A) for adding the respective polarized components of the intermediate frequency signals (e_S and e_P) from said detecting circuit (9);
a control circuit (11B) for controlling said optical local oscillating circuit (7) depending on the added output of said adding circuit (11A); and
detecting output signal modulating means (14) for modulating either of the detected outputs (e_S and e_P) of the respective polarized components from said detecting circuit (9).

17. A polarized wave diversity optical receiver for coherent optical communication according to claim 16, wherein said mixing circuit (8) splits the signal light transmitted through said optical fiber (5) and said local oscillating light from said optical local oscillating circuit (7) into two types of polarized components, respectively, and then, mixes the same polarized components to output.

18. A polarized wave diversity optical receiver for coherent optical communication according to claims 1, 10 or 16, wherein said mixing circuit (8) mixes the signal light transmitted through said optical fiber (5) and said local oscillating light from said optical local oscillating circuit (7), and then, splits the mixed signal into two types of polarized components to output.

19. A polarized wave diversity optical receiver for coherent optical communication according to claim 16, wherein said detected output signal modulating means (14) is the one for modulating the phase of either of the detected output signals (e_S and e_P) of the respective polarized components.

20. A polarized wave diversity optical receiver for coherent optical communication according to claim 16, wherein said detected output signal modulating means (14) is the one for substantially shifting the phase of either of the detected output signals (e_S and e_P) of the respective polarized components.

21. A polarized wave diversity optical receiver for coherent optical communication according to claim 16, wherein said detected output signal modulating means (14) is the one for modulating the frequency of either of the polarized components.

22. A polarized wave diversity optical receiver for coherent optical communication according to claims 10 or 16, wherein when the power of said signal light is assumed to be 1, the power distribution of the polarized components is expressed in such a way that the power of one of the polarized components is a and the other is (1-a), and the power distribution of the two types of polarized wave components of said local oscillating light are the same (each being 1/2).

23. A polarized wave diversity optical receiver for coherent optical communication according to claims 12 or 19, wherein the phase modulating by means of said phase modulating means (13) is carried out by changing in time.

24. A polarized wave diversity optical receiver for coherent optical communication according to claims 3, 11, 14 or 19, wherein said signal light is FSK modulated signal or ASK modulated signal.

25. A polarized wave diversity optical receiver for coherent optical communication according to claim 17, further comprising doublers for doubling the frequencies of the signals before inputting into said adding circuit to cancel the phase information.

26. A polarized wave diversity optical receiver for coherent optical communication according to claims 12, 13, 14, 17 or 18, further comprising doublers for doubling the frequencies of the signals before inputting into said adding circuit to cancel the phase information.

27. A polarized wave diversity optical receiver for coherent optical communication according to claims 8 or 25, wherein said signal light is PSK modulated signal or DPSK modulated signal.

Fig. 1

COHERENT OPTICAL COMMUNICATION SYSTEM

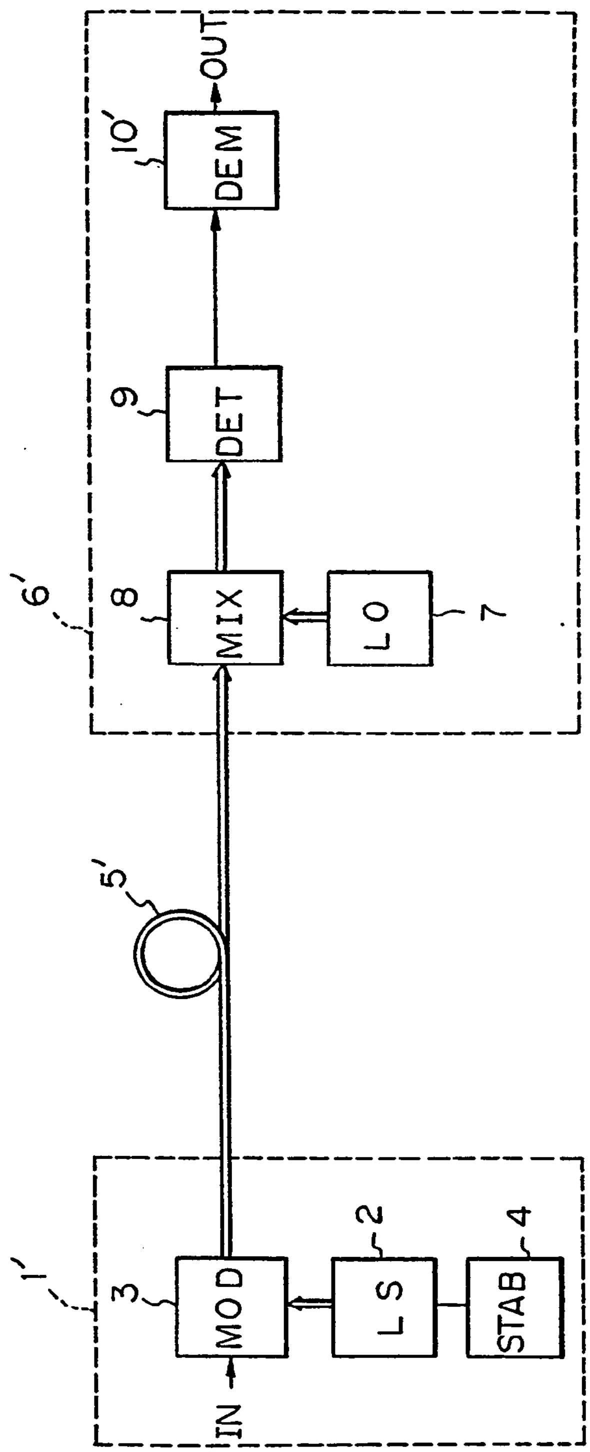
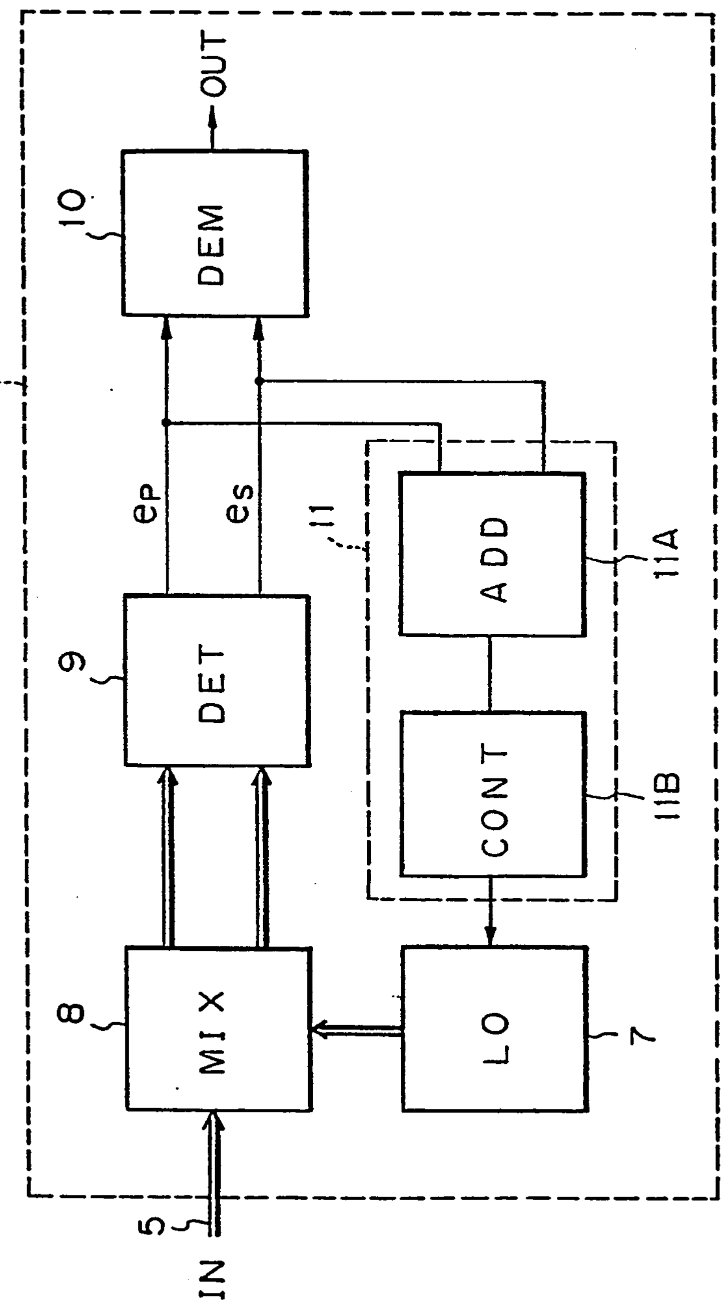


Fig. 2

OPTICAL RECEIVER



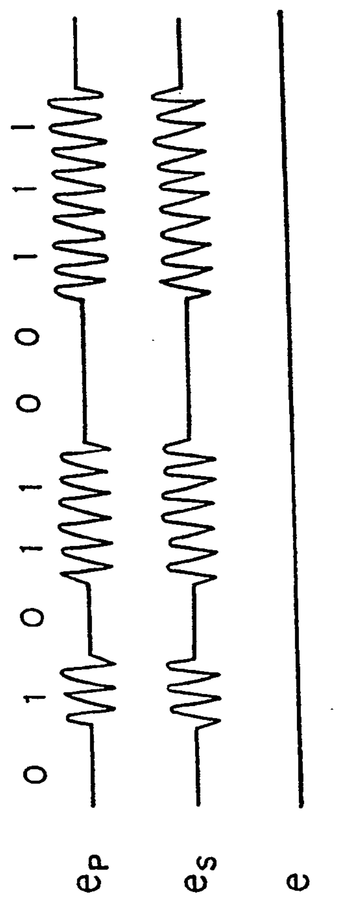


Fig. 3A
Fig. 3B
Fig. 3C

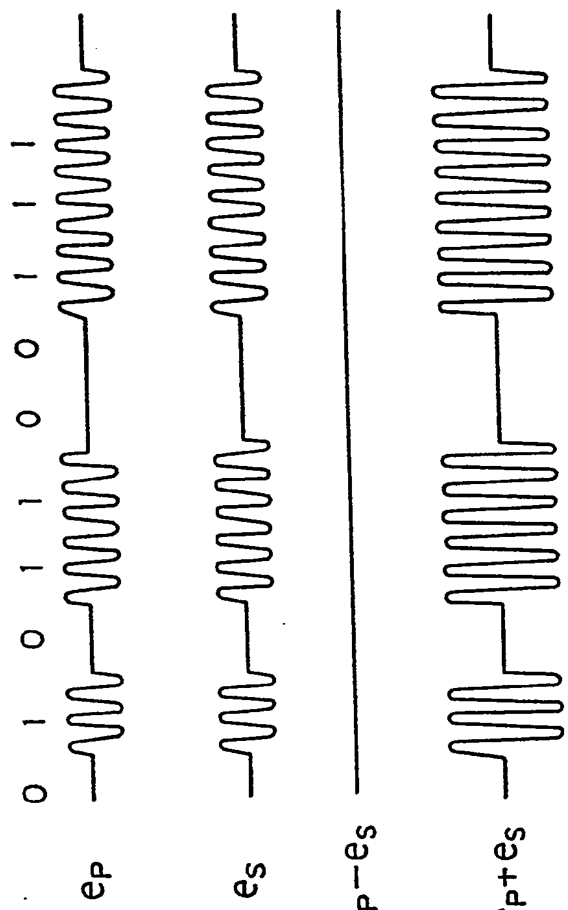


Fig. 9A
Fig. 9B
Fig. 9C
Fig. 9D

Fig. 4

1st PRINCIPLE OF INVENTION

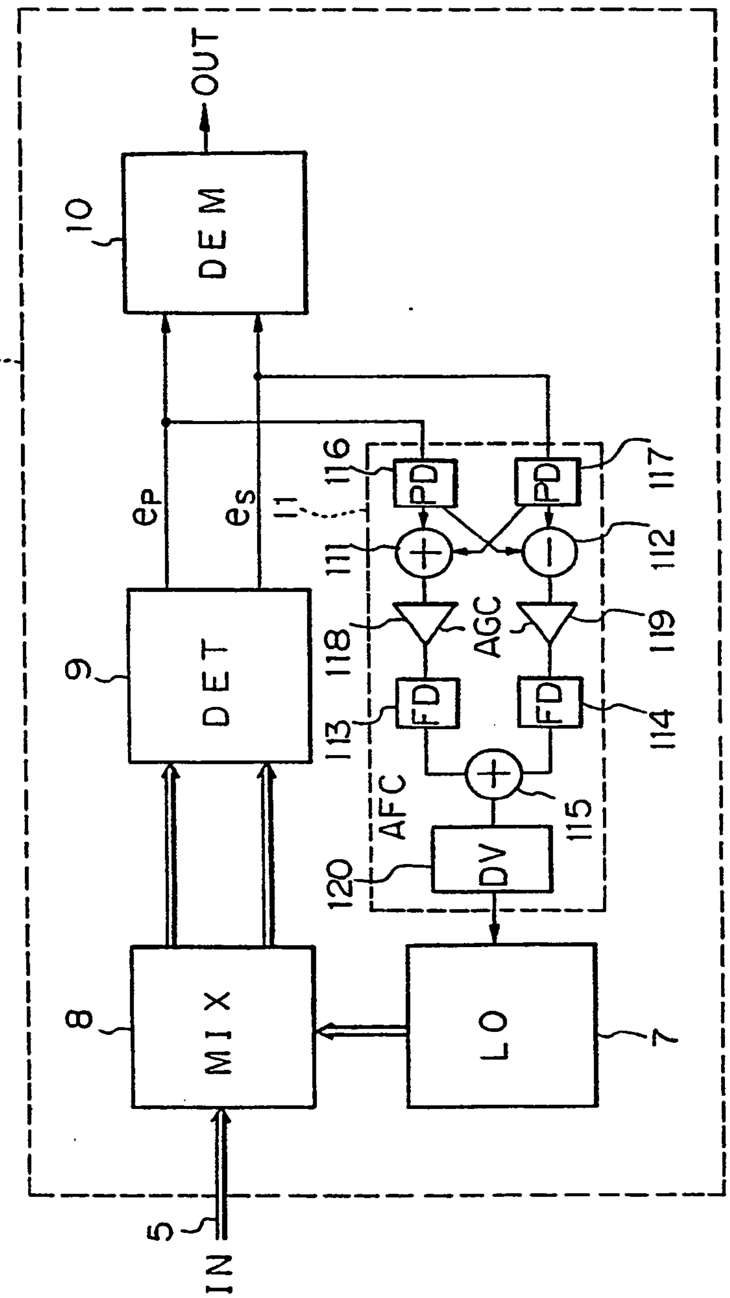


Fig. 5

2nd PRINCIPLE OF INVENTION

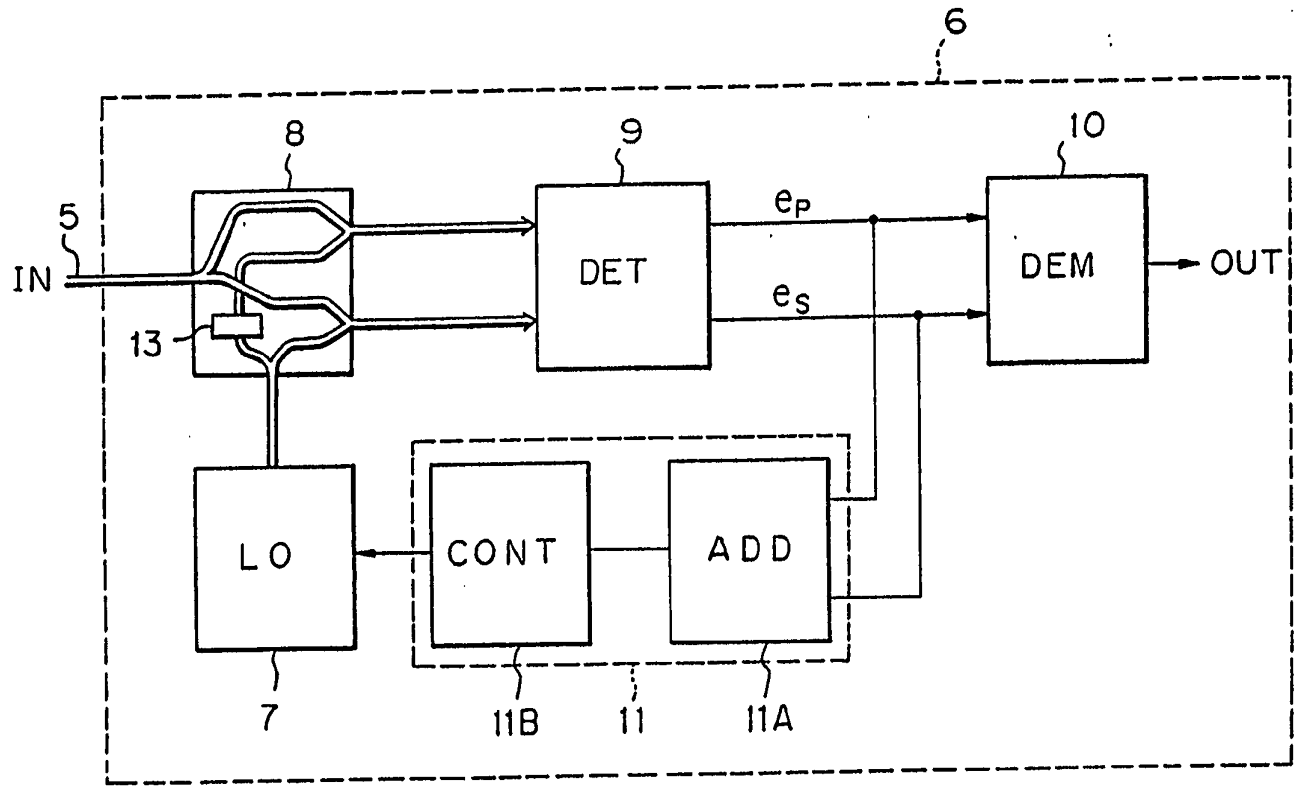


Fig. 6

3rd PRINCIPLE OF INVENTION

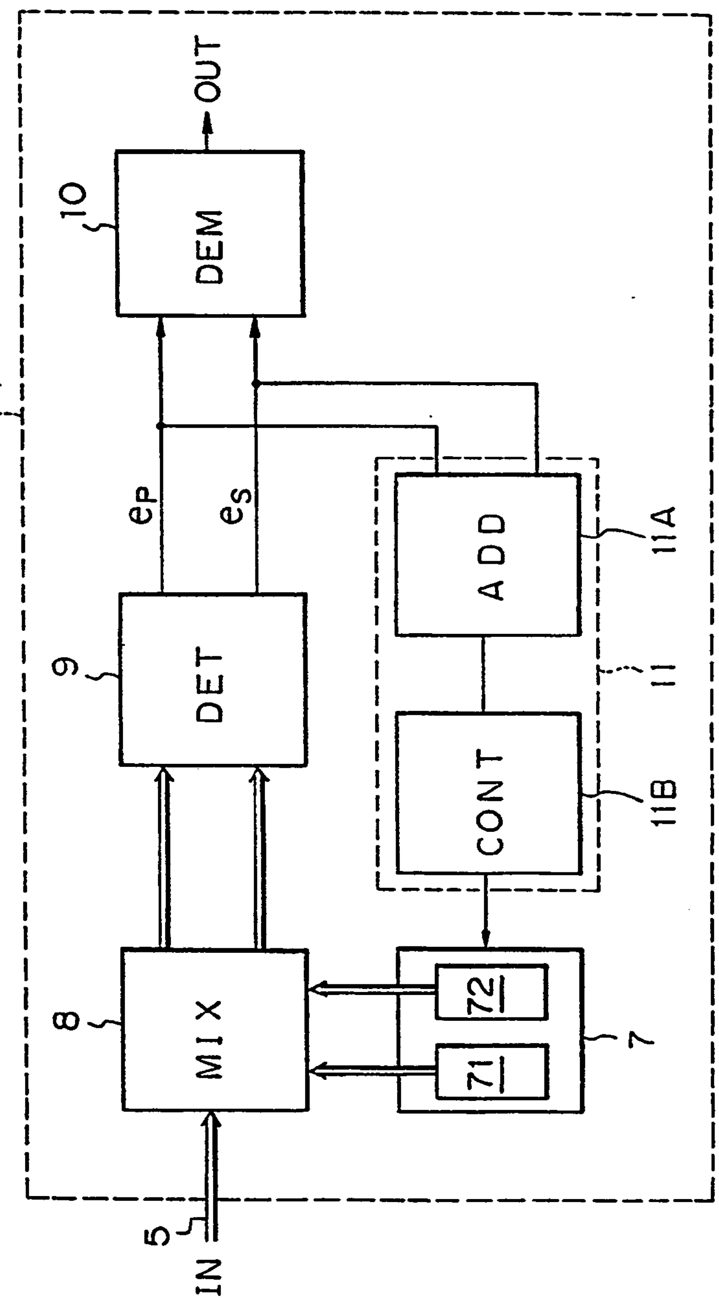


Fig. 7

4th PRINCIPLE OF INVENTION

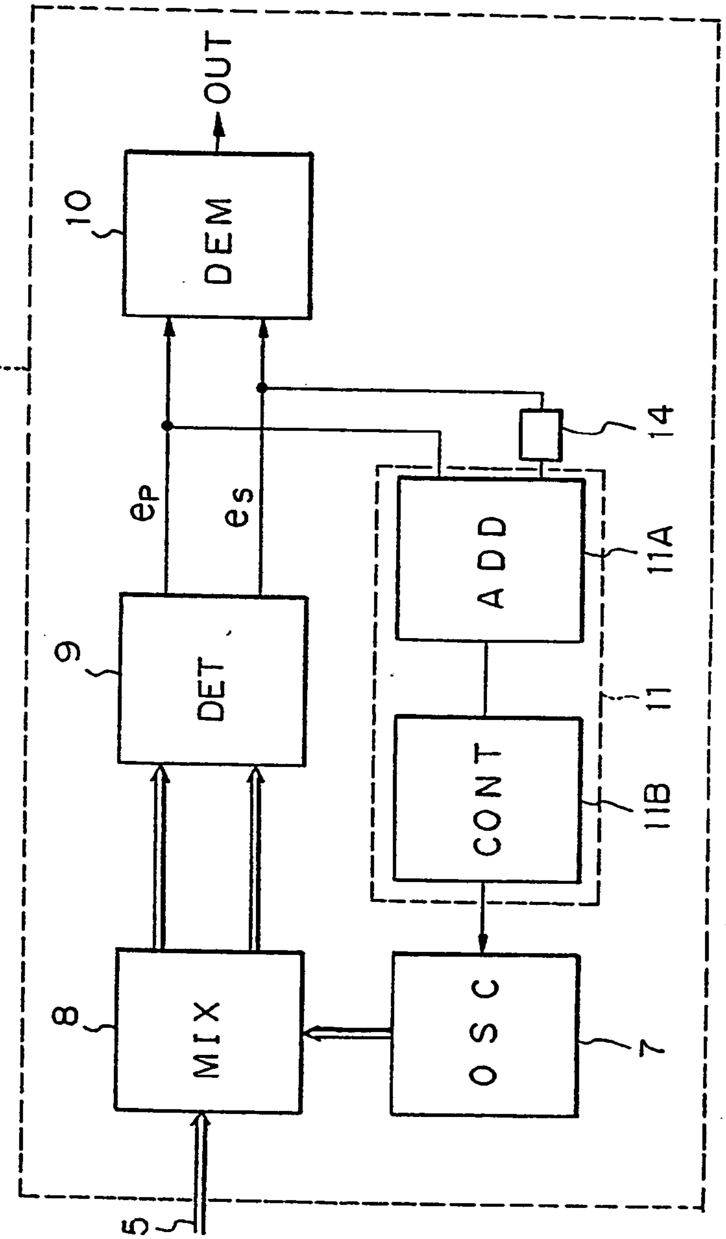
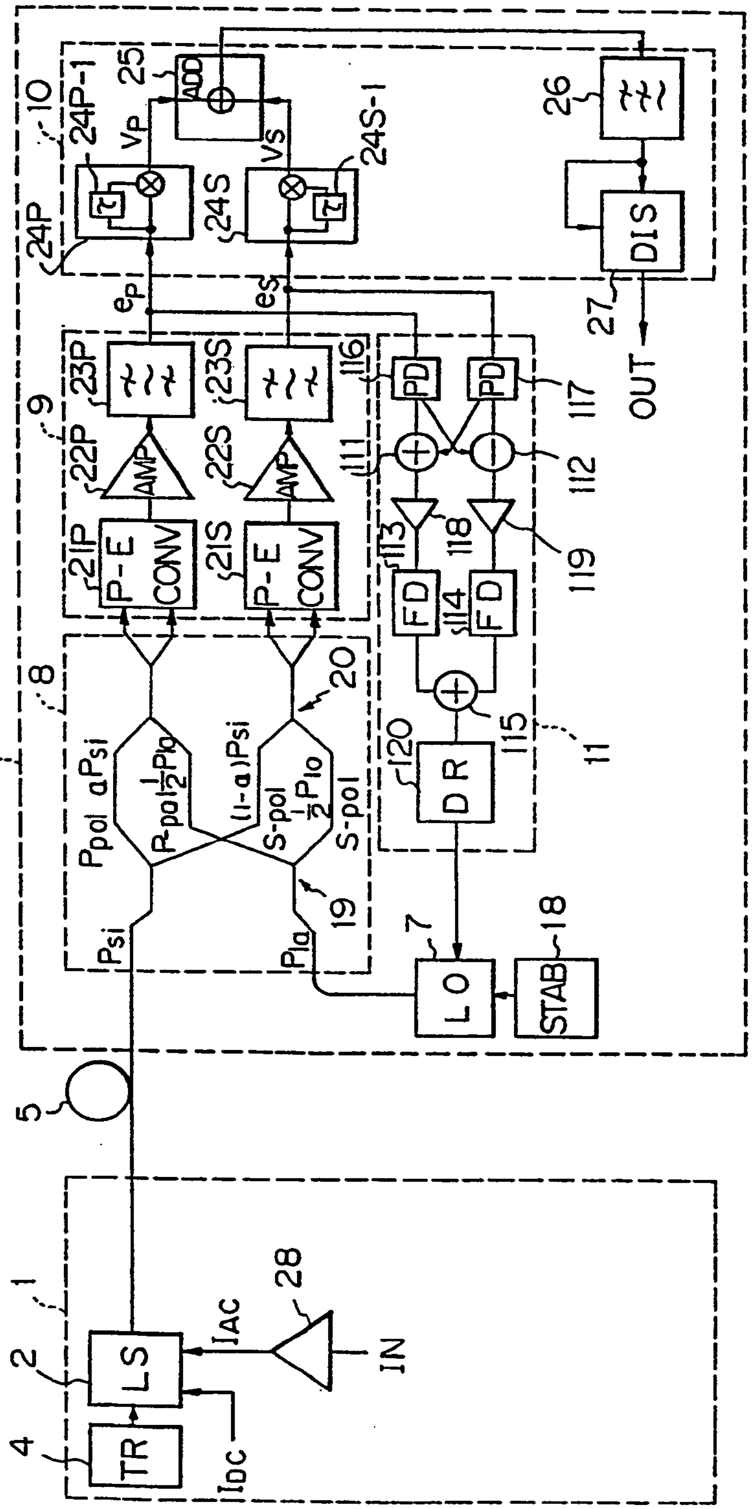


Fig. 8

1st EMBODIMENT (SUM & DIFFERENCE , FSK)



2nd MODE IN 1st EMBODIMENT

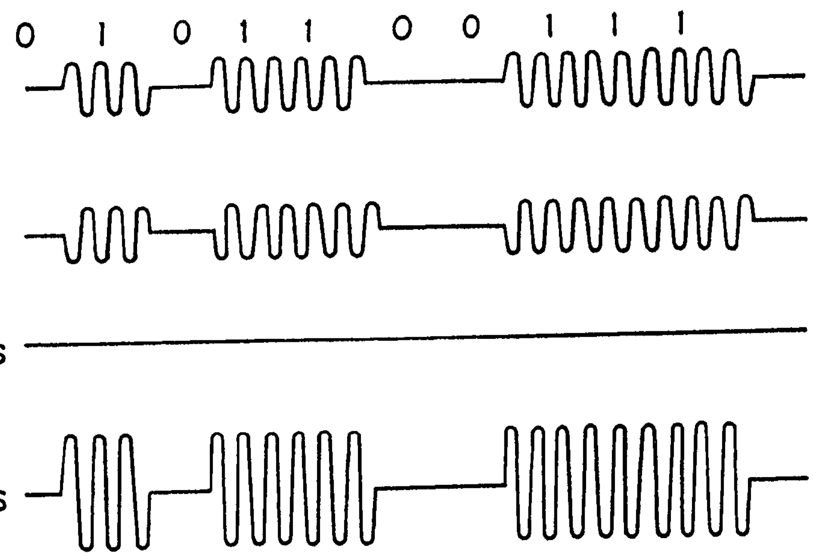


Fig. 10A

Fig. 10B

Fig. 10C

Fig. 10D

Fig. 11

2nd EMBODIMENT (DELAY BEFORE SUM AND DIFFERENCE FSK)

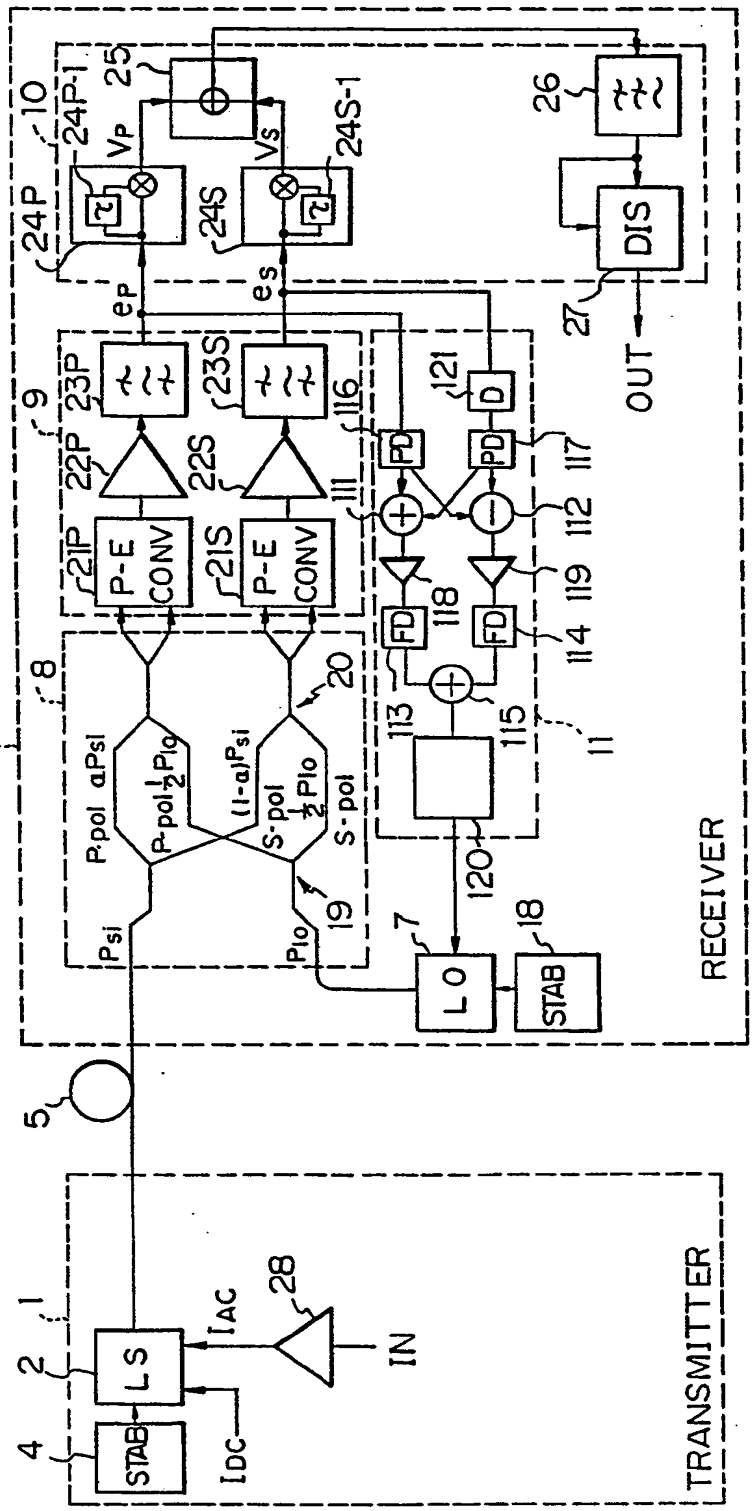


Fig. 12

3rd EMBODIMENT (DOUBLE BEFORE SUM AND DIFFERENCE, DPSK)

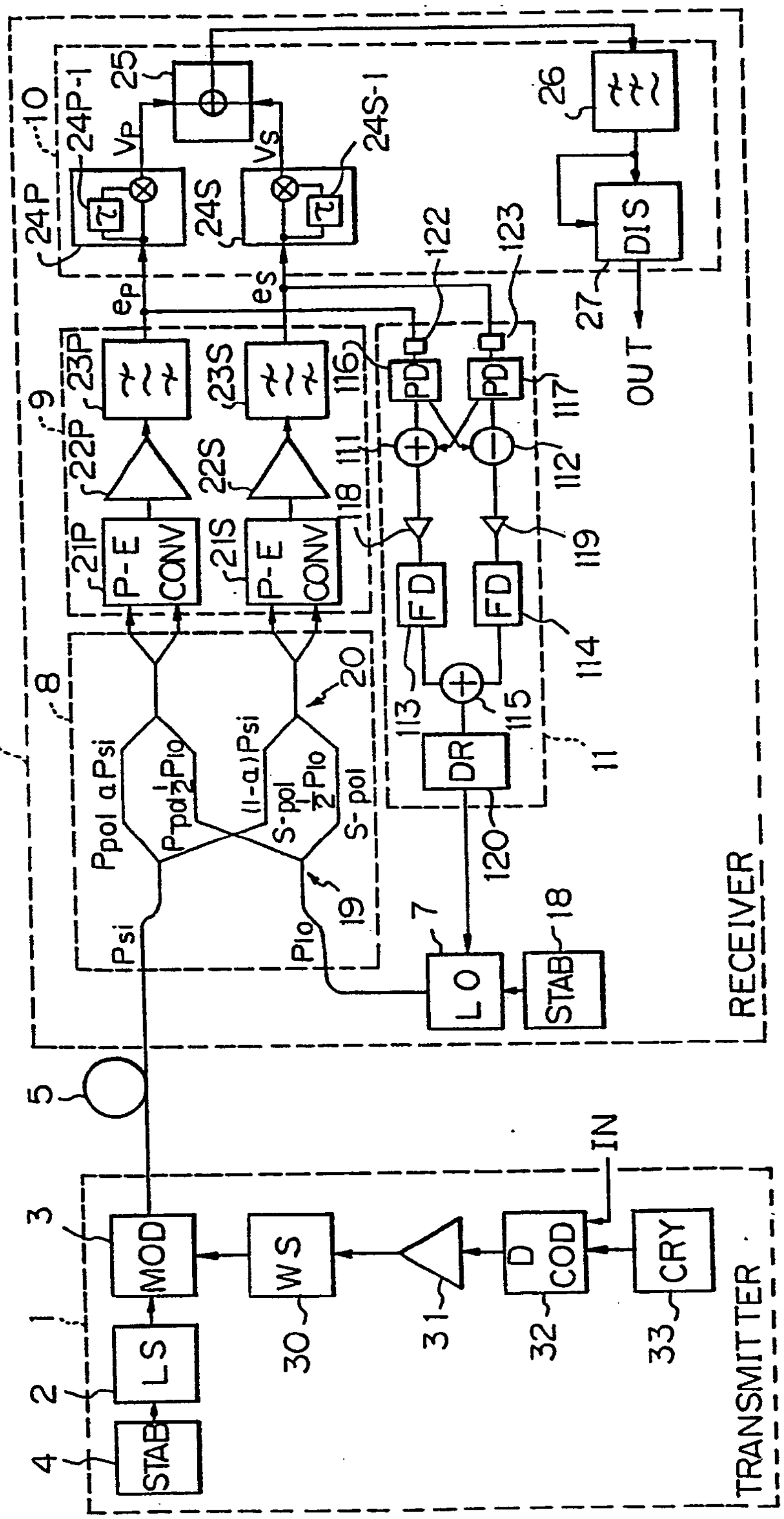


Fig. 13

4 th EMBODIMENT (DELAY AND DOUBLERS BEFORE SUM AND DIFFERENCE, DPSK)

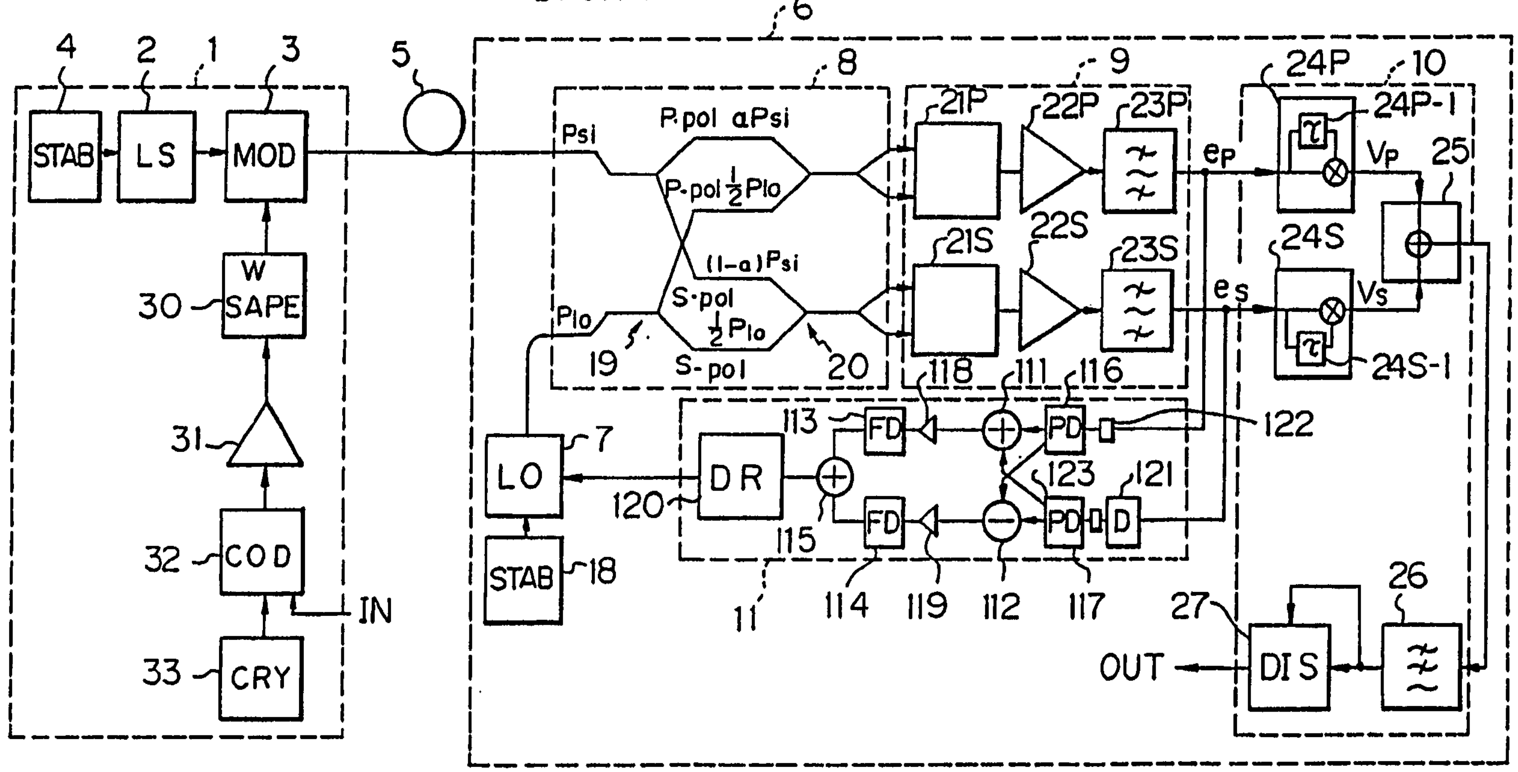


Fig. 14

5th EMBODIMENT (POLARIZED COMPONENT MODULATION, FSK)

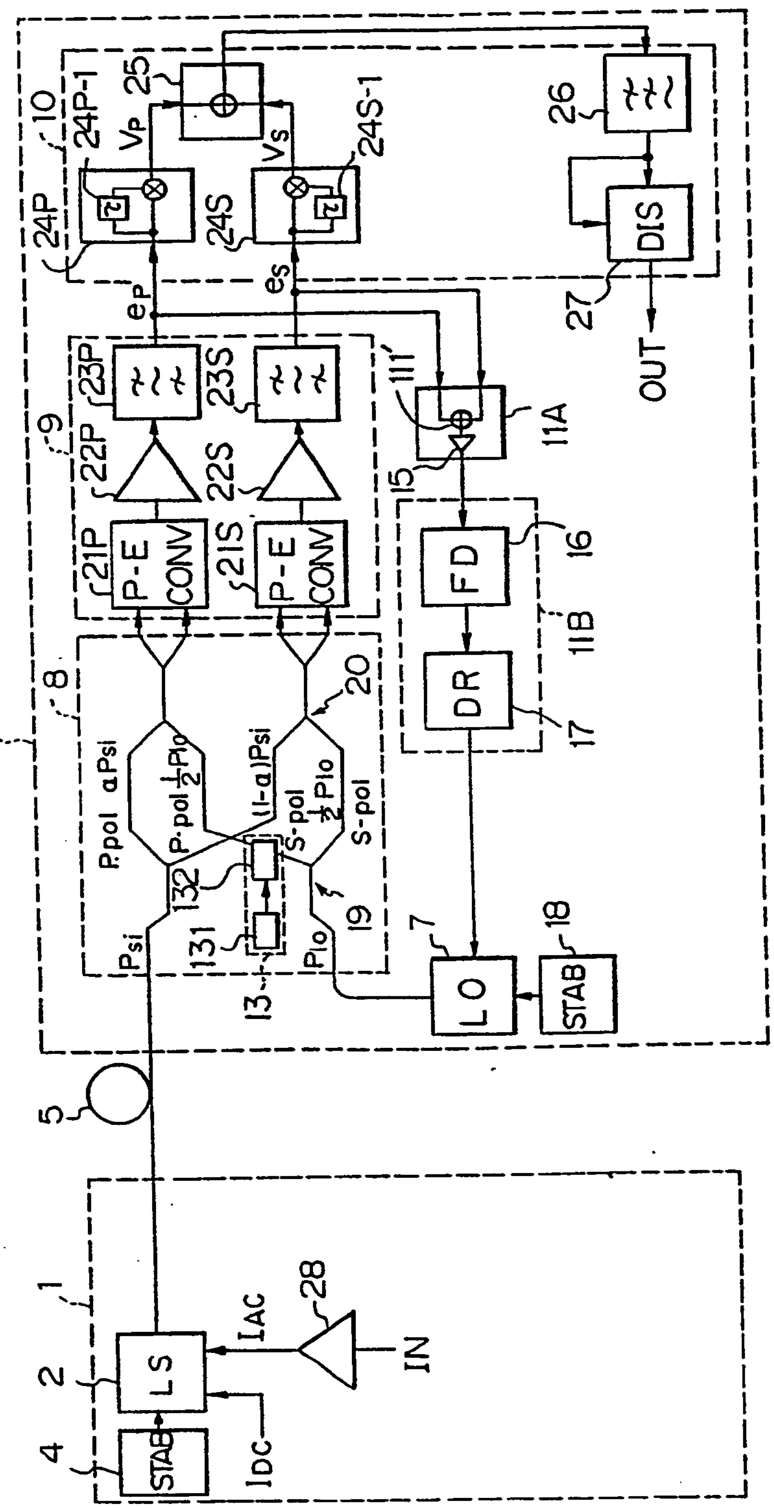


Fig. 15

6th EMBODIMENT (POLARIZED COMPONENT MODULATION BY SEMICONDUCTOR LASERS , FSK)

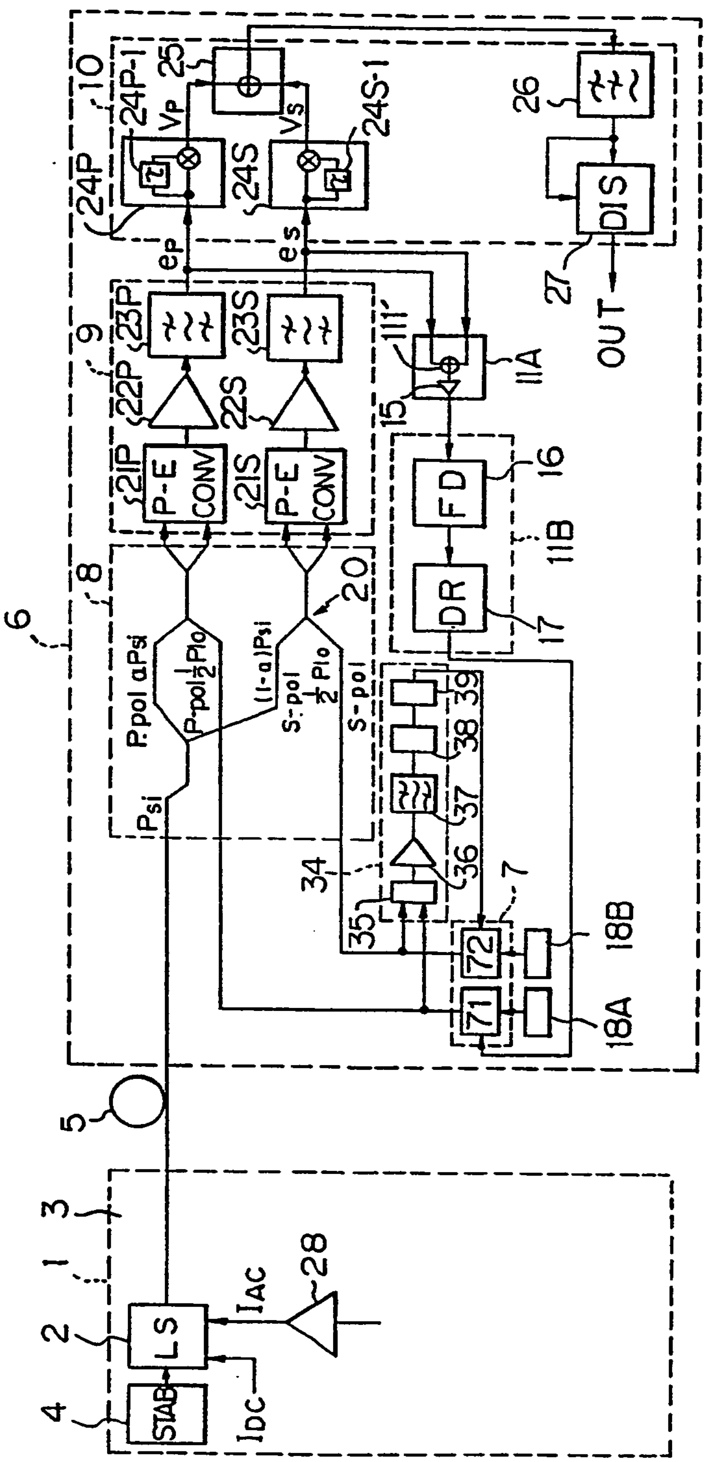


Fig. 16

7th EMBODIMENT (DETECTED COMPONENT MODULATION, ISK)

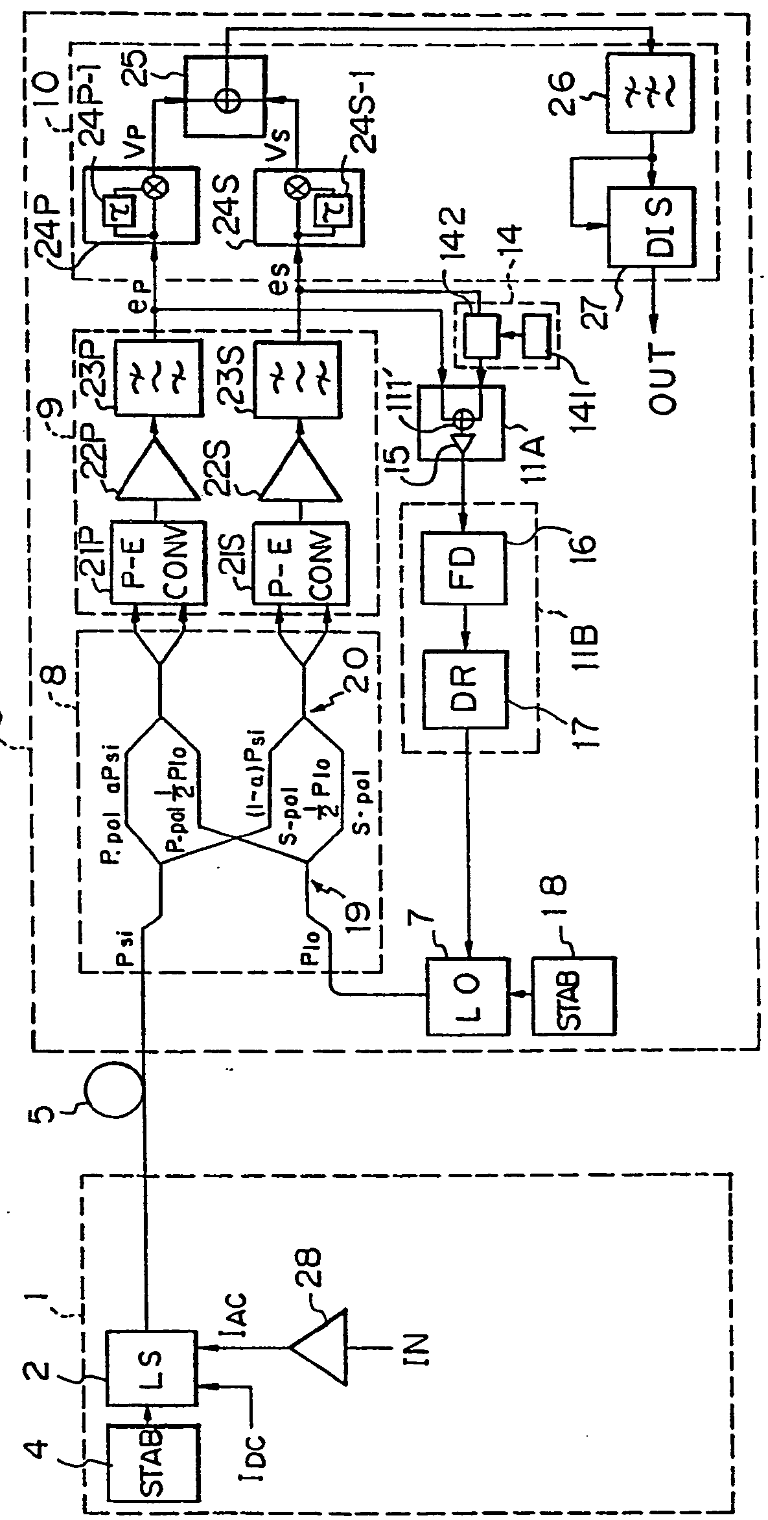


Fig. 17

8 th EMBODIMENT (POLARIZED COMPONENT MODULATION, DPSK)

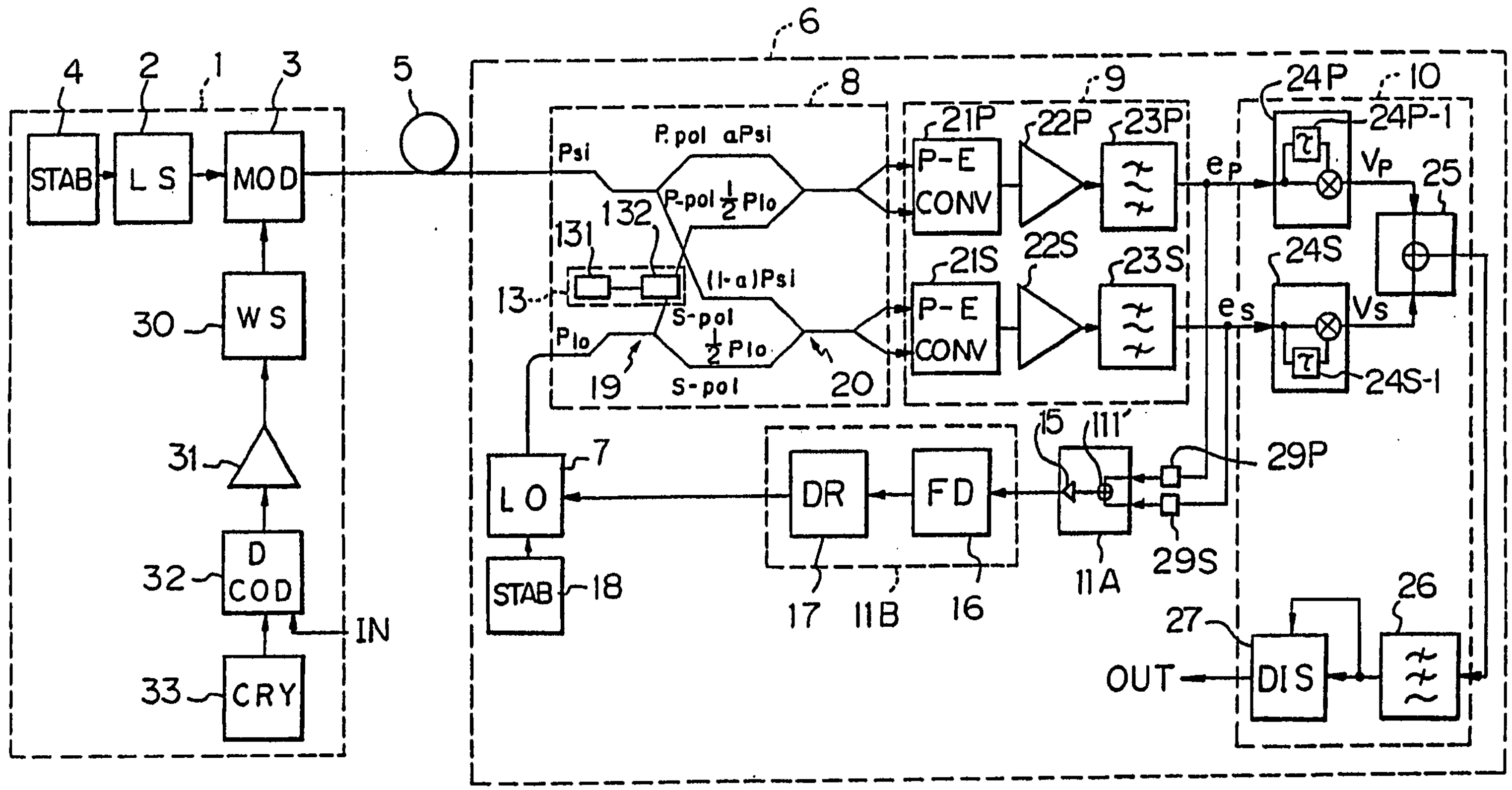


Fig. 18

9 th EMBODIMENT (POLARIZED COMPONENT MODULATION BY SEMICONDUCTOR LASERS, DPSK)

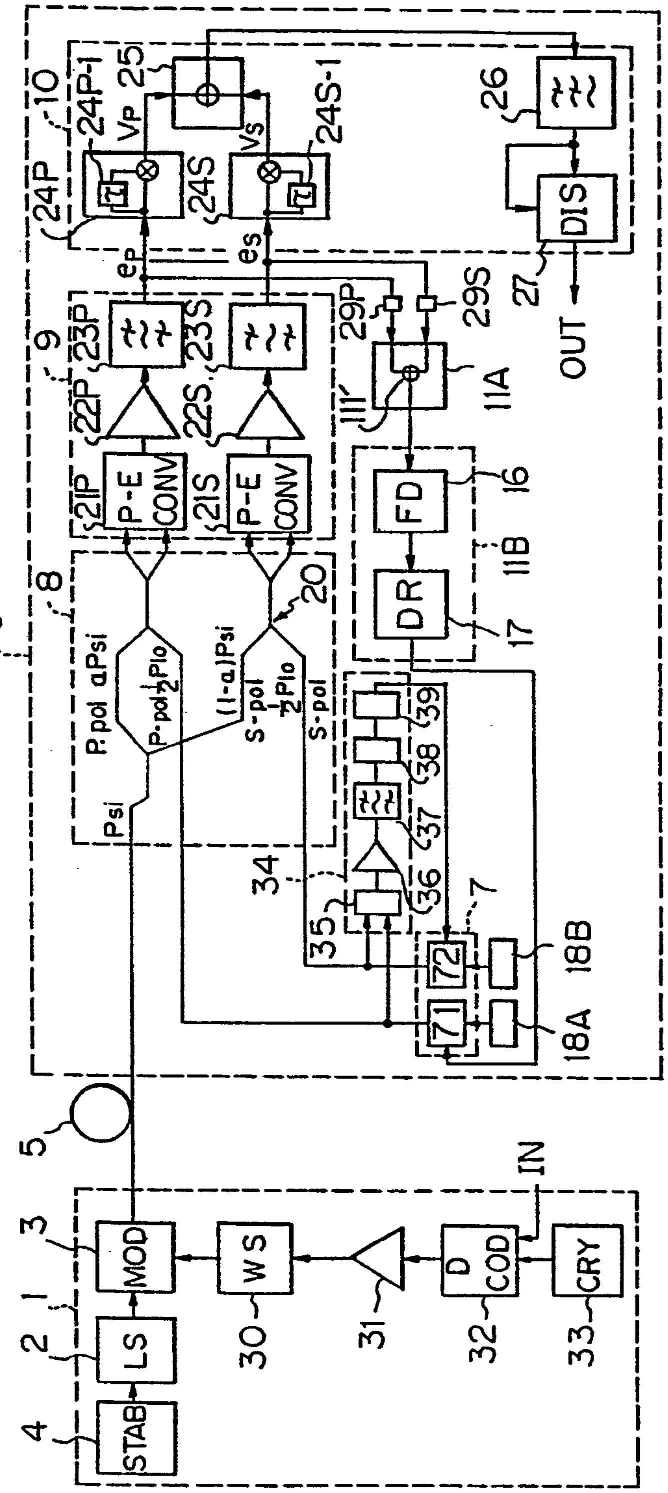


Fig. 19

TENth EMBODIMENT (DETECTED COMPONENT MODULATION, DPSK)

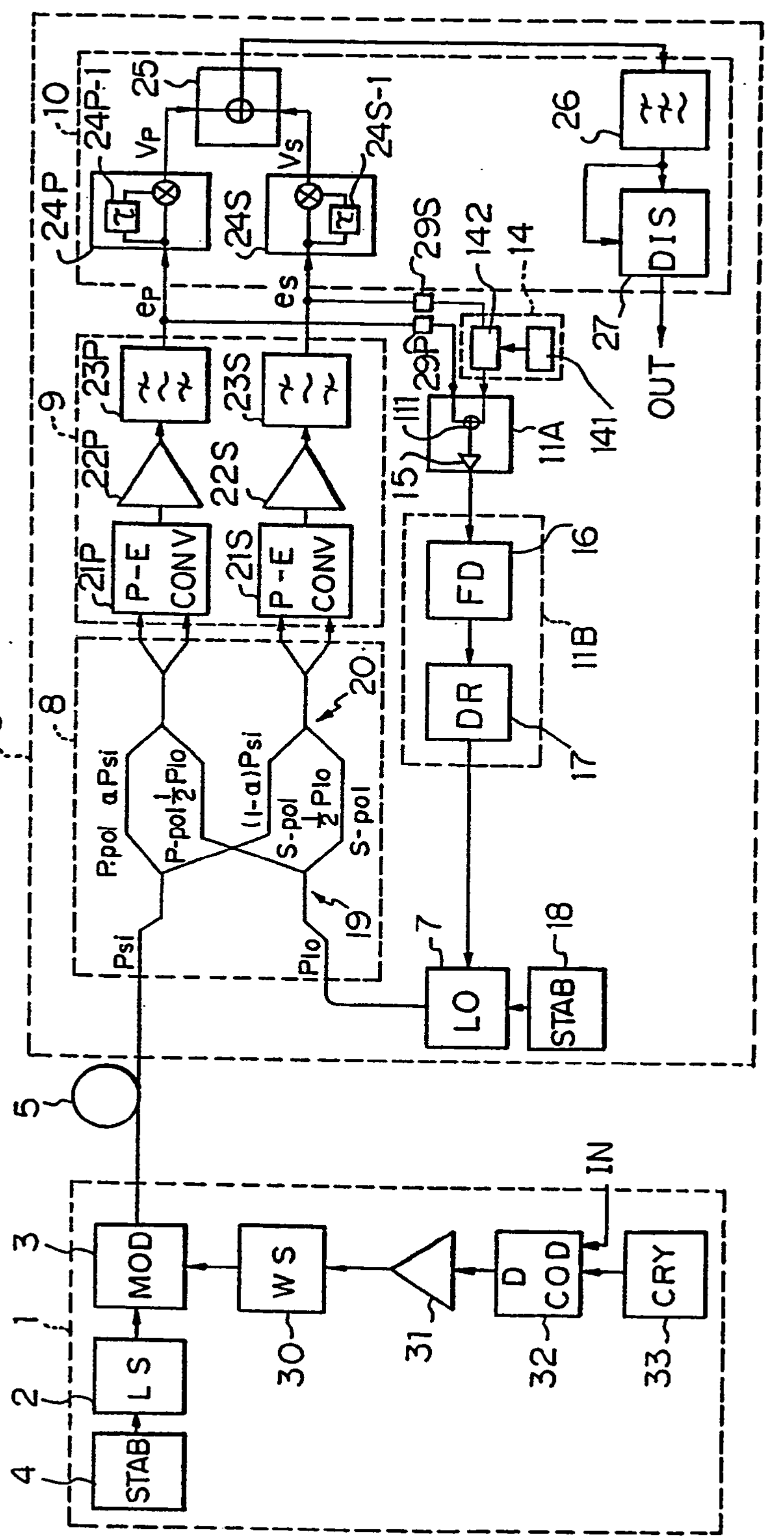
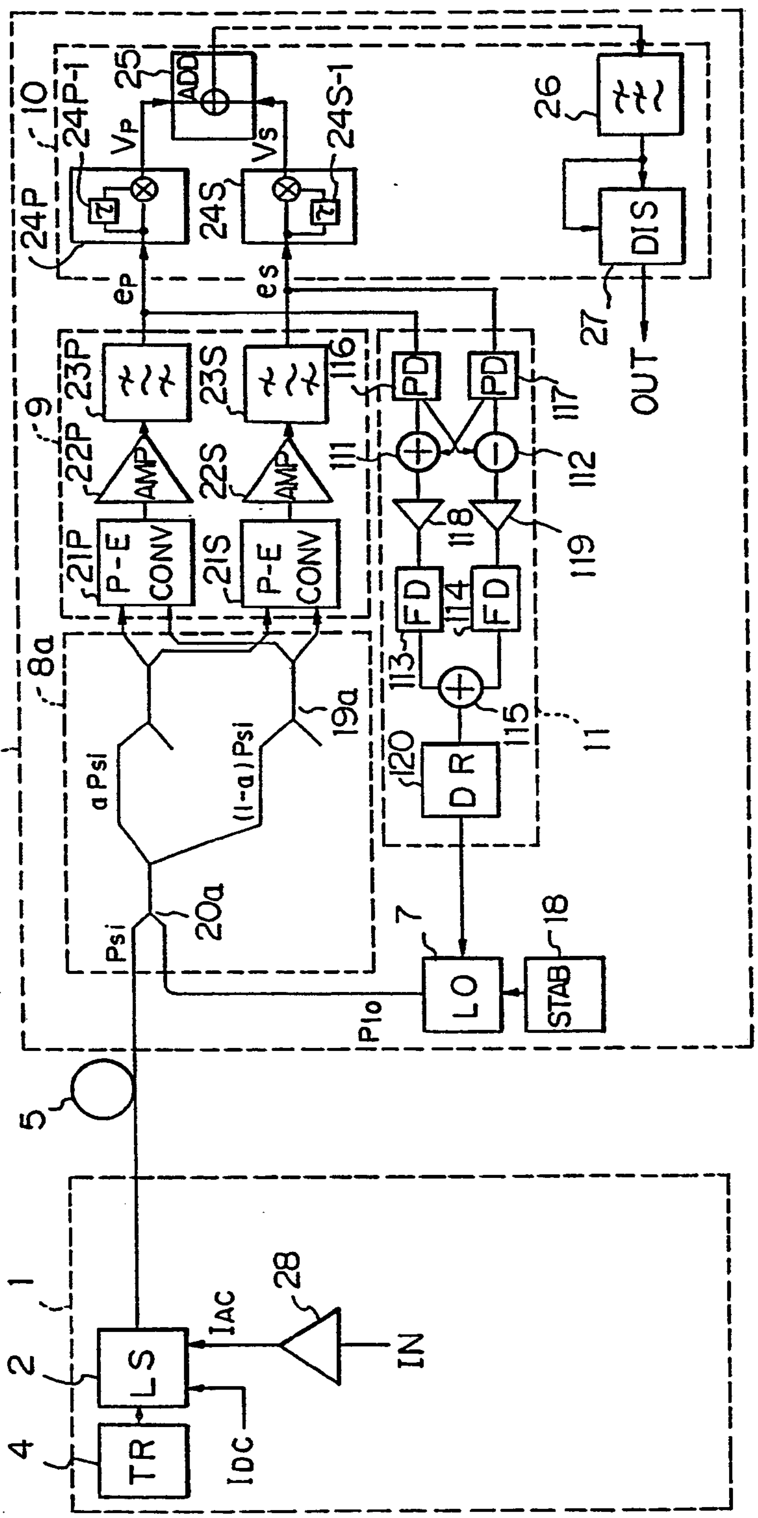


Fig. 20

MODIFICATION OF 1st EMBODIMENT (SUM & DIFFERENCE, FSK)



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(54) **Polarization diversity optical receiver for coherent optical communication.**

(57) Disclosed is a polarized wave diversity optical receiver for coherent optical communication comprising: an optical local oscillating circuit (7) for oscillating local oscillating light; a mixing circuit (8) for mixing signal light and the local oscillating light to obtain two polarized components; a detecting circuit (9) for detecting the polarized components to output intermediate frequency signals (e_S and e_P); and a frequency control circuit (11) for controlling, in accordance with the intermediate frequency signals (e_S and e_P), the oscillating frequency of the optical local oscillating circuit (7). To ensure that the intermediate frequency is not disappeared, the frequency control circuit (11) outputs a combined signal of a sum and a difference of said intermediate frequency signals (e_S and e_P).

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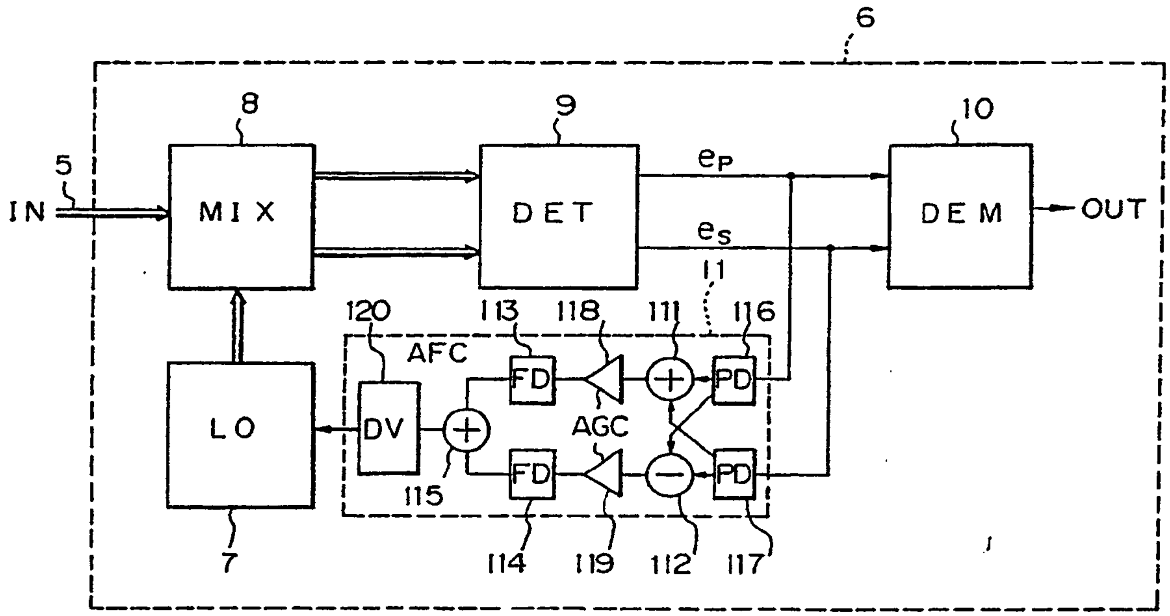
Fig. 4

1st PRINCIPLE OF INVENTION



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 89 10 2811

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US-A-4 723 315 (WETHERELL) * Column 3, line 53 - column 4, line 2; column 9, lines 28-40; Figures 10,11 * – – –	1-27	H 04 B 9/00
A	ELECTRONICS LETTERS, vol. 23, no. 25, 3rd December 1987, pages 1382-1384, Stevenage, GB; S. RYU et al.: "Polarisation-insensitive operation of coherent FSK transmission system using polarisation diversity" * Page 1382, right-hand column, line 39 - page 1383, left-hand column, line 2; figure 1 * – – –	1-27	
A	JOURNAL OF LIGHTWAVE TECHNOLOGY, vol. LT-5, no. 2, February 1987, pages 274-276, New York, US; B. GLANCE: "Polarization independent coherent optical receiver" * Page 274, right-hand column, lines 6-16; figure 1 * – – –	1,10,16	
A	US-A-4 506 388 (MONERIE et al.) * Column 2, line 65 - column 3, line 36; column 4, lines 28-31; figure * – – –	1-27	
A	JOURNAL OF LIGHTWAVE TECHNOLOGY, vol. LT-5, no. 4, April 1987, pages 561-572, New York, US; A.W. DAVIS et al.: "Phase diversity techniques for coherent optical receivers" * Page 564, right-hand column, lines 15-17; figure 2 * – – –	1,8,10,16, 26	**TECHNICAL FIELDS SEARCHED (Int. Cl.5)** H 04 B G 02 F
A	THIN SOLID FILMS, ELECTRONICS AND OPTICS, vol. 126, no. 3/4, 26th April 1985, pages 167-176, Lausanne, CH; R.C. BOOTH et al.: "LiNbO3 integrated optic devices for coherent optical fibre systems" * Page 171, lines 30-35 * – – – –/–	10	

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	03 September 91	WILLIAMS M.I.

CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

Application Number

EP 89 10 2811

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
P,X	PROCEEDINGS OF THE FOURTEENTH EUROPEAN CONFERENCE ON OPTICAL COMMUNICATION, Brighton, 11th - 15th September 1988, part 1, pages 90-93; S. WATANABE et al.: "Polarisation-insensitive 1.2 Gb/s optical DPSK heterodyne transmission experiment using polarisation diversity" * Page 91, lines 11-22; figure 1 * ---	16,17,19	
P,A	IDEM -----	1-15,18, 20-27	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)

The present search report has been drawn up for all claims

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